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A LITERATURE REVIEW ON HELICOPTER NAVIGATION. (U)
APR 79 A T BUCKLER, N A JOHNSON, A M POSTON

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(10) Andrew T. Buckler,
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Clarence A. Fry

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This literature review should provide useful background information to define issues which are related to terrain flight operations. There are 210 sources of literature cited which discuss issues relevant to helicopter navigation.

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A LITERATURE REVIEW ON HELICOPTER NAVIGATION

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April 1979

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INTRODUCTION

The advent of terrain flight techniques in Army aviation poses unique problems to navigation and geographic orientation. The US Army Human Engineering Laboratory (USAHEL) consider that an extensive review of the literature provided here will afford useful background to define the issues related to terrain flight operations. There are 210 sources of literature cited here which discuss issues relevant to helicopter navigation.

The references are categorized into seven categories to afford the user with ready access to specialized helicopter navigation issues. These categories are:

I. Air Navigation Techniques—General overview of various navigation techniques.

II. Systems Descriptions and Evaluations—Technical descriptions and test reports of specific navigation systems.

III. Navigation Displays—Includes pictorial displays, contact analog, trajectory error, etc. (Also see Chapter IV—Map Displays)

IV. Maps and Map Displays

V. Avionics Equipment—Includes avionics packages, horizontal situation indicators, compasses and hover displays.

VI. Research Methodology, Performance Measurement, Simulation, and Training

VII. Symposium and bibliographics relating various topics in navigation.

CHAPTER I

AIR NAVIGATION TECHNIQUES

The literature in this chapter addresses the evaluation of air navigation techniques. The information is presented in two sections:

A. General

B. Low-Level

Air navigation has progressed from crude techniques of visually following roads, waterways and other man-made or natural terrain features to sophisticated self-contained or externally referenced navigation systems. The development of all weather flying necessitated the development of navigation systems which did not require visual reference to the ground. Specialized aeronautical charts which facilitate both navigation referenced to ground features and electronic navigation techniques were also developed.

The extremely low level flight regime used in US Army helicopter operations modifies the perspective of terrain features. These altitudes also present problems to line-of-sight radiation devices used in many navigation and terminal area systems. Some of the issues related to this form of navigation are addressed in the second section of this chapter.

A. GENERAL NAVIGATION

1. Anderson, E. W. Air navigation techniques. Journal of the Institute of Navigation, 1971, 18, 77-92.

The history of air navigation systems and techniques is traced from World War I through World War II, the formation of the Institute for Navigation, and up to the present time. Doppler, VOR, ADF and Loran navigation systems are briefly described along with various techniques of air traffic control and automatic flight. Some thoughts on the future of navigation are also presented.

2. Anderson, E. W. The principles of navigation. New York: American Elsevier, 1966.

This book presents a very broad overview of navigation theories and practices as they apply to both air and sea navigation. The author presents the case for an essential unity of philosophy underlying all of the widely varying navigation techniques and systems. The principles of navigation are presented in a form that may be acceptable to the airman or seaman, as well as the scientist or engineer.

3. Brewin, E., & Wright, D. L. Low cost self-contained solutions to the navigation problem in rotary and fixed-wing aircraft. AGARD-CPP-176, September 1975.

4. Chin, J. W., & Weaver, R. E. Systems approach to practical navigation. AGARD-CPP-176, September 1975.

5. Daniels, T. Potential Army navigational systems. In Proceedings of a Symposium on Staying Power. Ft. Rucker, AL: Army Aviation Center, July 1975.

6. Hessel, A., & Eckel, W. Continuous navigation updating method by means of area correlation. AGARD-CPP-176, September 1975.

7. Hoffman, C. S., & Czaja, J. J. Man's future role as an aircraft navigator. Journal of the Institue of Navigation, 1970, 17, 404-411.

This paper explores the role of man as a navigator in commercial and military aircraft. Performance of the crew's functions is considered in terms of the increasing stringency of requirements and the growing availability of navigation aids. These aids include sensors, information processing methods, and displays. The navigation task and some of the advanced means used in its performance are discussed for the environments of long-range flight, terminal areas, and specialized military missions. An evolutionary development has occurred during the past generation with respect to commercial and military requirements, technology, and the crew's navigation functions. This development can be expected to continue into the future.

8. Inglefield, W. J. Automation in aircraft navigation. Journal of the Institute of Navigation, 1967, 20, 496-507.

9. Kayton, M., & Fried, W. Avionics navigation systems. New York: Wiley & Sons, 1969.

This book presents a unified treatment of the principles and practices of modern aircraft navigation systems. A new era in navigation has dawned with the appearance of complex sensor/computer systems. This book treats these systems as providing information to the aircrew. Both state-of-the-art and developmental systems are discussed in a manner designed to serve a broad range of readers from navigation system engineers to operations personnel.

10. Penfold, T. J. Medium accuracy, low cost navigation systems for helicopters. AGARD-CPP-176, September 1975.

11. Tayler, J. A. A survey of low cost self-contained navigation systems and their accuracies. AGARD-CPP-176, September 1975.

12. Taylor, M. An optimum military helicopter navigation system. AGARD Conference Proceedings 86-71, September 1971.

A low-cost all-weather, self-contained navigation system is necessary in order to fully exploit the many military capabilities of helicopters. Inertial, Doppler-Magnetic, and Doppler-Gyroscopic Navigation systems are analyzed to determine parametric requirements (such as gyro drift, torque scaling, and computer requirements) as a function of navigation accuracy. A study of these alternate candidate systems indicates an optimum approach is the combination of Doppler velocity with an accurate heading indicator utilizing low drift gyroscopes that can rapidly gyro-compass to true North during ground alignment. For sub-sonic application less precise gyro drift is required with this approach than for an equivalent all-inertial system. The various system configurations are functionally defined and cost vs. performance analysis using typical parameters is performed for the alternate candidate systems.

13. Thorne, T. G., (Ed.). Navigation systems for aircraft and space vehicles. New York: MacMillan, 1962.

This book presents a collection of papers describing a wide range of systems designed for airborne navigation. Systems described include various radio navigation systems, LORAN-C, Dectra, Doppler and ground-aided navigation systems. Air traffic control and the use of satellites in navigation are also discussed.

14. Watts, A. C. D. Lightweight medium accuracy low cost navigation: Highlighting of key characteristics. AGARD-CPP-176, September 1975.

15. Winick, A. B. Air navigation trends. Journal of the Institute of Navigation, 1968, 15, 78-81.

This paper proposes that the central concern of air navigation in the modern era is no longer simply finding the way to a destination. Rather, attention now focuses on navigation accuracy. Other general trends in air navigation are also discussed, such as long distance navigation, redundant navigation aids, sensor integration, short distance navigation, pictorial displays, collison prevention systems and all weather landing programs.

16. Wright, R. H. Orientation systems: First things first. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, D C : JANAIR, 1969.

Dr. Robert H. Wright reviewed the geographic orientation requirements for Army pilots flying light aircraft. The need for a thorough system analysis was described and the need for a complete understanding of the pilot's role in the system was stressed. Dr. Wright described the operating environment of Army aviation and discussed the need for simple equipment and the special requirement for close-in geographic orientation during helicopter operations. Radar/map terrain correlation by the crew, using perceptual pattern matching, was cited as an example of crew capabilities that could not be automatically accomplished without highly complex equipment.

B. LOW LEVEL NAVIGATION TECHNIQUES

1. Gray, T., Waller, G., & Wright, R. Techniques for low altitude navigation: Direct estimation from tactical maps. (TR-67-4). Ft. Rucker, AL: Human Resources Research Office, April 1967.

The objective was to study the effects of map scale, map reference point variables, and training on the ability of pilots to estimate direction using Army tactical maps for low-level navigation. Twenty-four experienced officer and warrant officer pilot personnel working with various map reference point conditions made direction estimates using 48 maps with a scale of 1:100,000 and 48 maps with a scale of 1:250,000. The effect of training was studied by using a test-train-retest-delay-retest procedure. Performance was measured in terms of absolute error, in degrees, between the estimated direction and the correct direction. Analyses showed that averaged error in direction estimation using tactical maps was reduced significantly by training, dropping from a mean of 6.1^{o} before training to 4.8^{o} after training. There were also signficant differences in accuracy of direction estimates as a function of map scale, distance between reference points, and compass octant in which the reference points were located.

2. Johnson, N., & Foster, M. Pilotage navigation utilizing a night-vision system (HEL-TM-6-77). Aberdeen Proving Ground, MD : US Army Human Engineering Laboratory, February 1977.

A field test was conducted to evaluate pilotage-navigation performance using a forward-looking infrared (FLIR) night-vision system. Two types of displays (helmet-mounted and panel-mounted) were used, each with three fields of view (FOV) (narrow, 15^{o} vertical x 20^{o} horizontal; medium, 30^{o} vertical x 40^{o} horizontal; wide, 45^{o} vertical x 60^{o} horizontal). The results indicate that the wide FOV is more effective than either of the narrower FOV's. The future TADS system is proposed to have a horizontal FOV on the order of 40^{o}; the authors believe this will present serious problems in conducting pilotage navigation. The implications of these results are discussed.

3. Lewis, R. E. F., de la Riviere, W. E., & Sweeney, D. M. Dual versus solo pilot navigation in helicopters at low level. Ergonomics, 1968, 11, 145-155.

This study, using CH112 light helicopters and experienced pilots, was aimed toward answering two questions. Can the Army helicopter pilot navigate and simultaneously fly very low when, without the opportunity for briefing, he must fly between successive points in unfamiliar, relatively featureless terrain? Is navigation accuracy improved when the task is shared by two pilots forming a pilot and navigator team?

Six pilots participated in a comparison of solo and dual performance, in which 358 short tracks were flown in the course of 36 sorties. Each track could be described as a short flight in itself, since each was terminated by a landing. In the dual sorties, the task was shared by two pilots, one responsible for flying the helicopter, the other concerned solely with navigation.

No difference was found between dual and solo performance in terms of the numbers of endpoints reached (entering a circle of one-eighth mile radius at the endpoints). Advantages of a secondary nature, however, were shown for the dual teams, e.g., smaller errors in landings beyond the criterion circle, fewer initial heading errors and enroute 'sit downs'.

At the conclusion of the main trial a small test was conducted in which dual teams were permitted to fly routes of their choice as opposed to straight tracks. Although no statistical validity can be attached to the meagre post-trial data, it appears that improved performance is possible, but the duration of sorties may be greatly increased. Conclusions and recommendations are presented.

4. Martin, E. W. Treetop altitude navigation on reconnaissance missions: A report of tests. Paper presented at the Tenth Army Human Factors Research and Development Conference, Ft. Rucker, AL, 5-8 October 1964, 119-132.

5. Raju, G. V. S., & Horowitz, D. L. Man-machine considerations in system design for all-weather, low-level navigation. Journal of the Institute of Navigation, 1971, 17, 412-418.

This paper is concerned with man-machine considerations in system design for low-level navigation. In particular, computer generation of command information and visual display presentation are described. Simulated results are presented which indicate that the pilot's ability to fly on a given route is improved with the roll command display.

6. U. S. Army Avionics Laboratory. Low level night operations study. Summary Report (ECOM-4217). Ft. Monmouth, NJ: US Army Electronics Command, May 1974. (AD 919 652L)

This report presents the results of phase I of the low level night operations (LLNO) study program conducted by the avionics laboratory of the U.S. Army Electronics Command at Fort Monmouth, NJ. Results of flight tests, simulation, and a sensor measurements program are presented in summary form. The flight test portion of the program consisted of a comparative evaluation of various sensor/display configurations in the performance of terrain avoidance, terrain following, and precision hover maneuvers. The simulation effort examined terminal area maneuvers (precision hover, bob-up, sideward flight, and unattended landing) using a panel mounted CRT with various symbology sets and a helmet mounted display. The sensor measurement program obtained obstacle detection data from a variety of sensors under common test conditions for a set of obstacles ranging down to 1/8-inch field wire. In each of these areas, quantitative results are presented along with conclusions based on effectivity of the various systems tested.

7. U.S. Army Avionics Laboratory. Low level night operations study (ECOM-4417). Ft. Monmouth, N J : U.S. Army Electronics Command, June 1976. (AD 919 652)

This report presents the results of the Low Level Night Operations (LLNO) study program conducted by the Avionics Laboratory of the US. Army Electronics Command at Fort Monmouth, NJ. Results of flight tests, simulation experiments, and an extensive sensor measurements program are presented in summary form.

The flight test portion of the program consisted of a comparative evaluation of various sensor/display configurations in the performance of terrain avoidance, terrain following, and precision hover maneuvers. The simulation effort examined terminal area maneuvers (precision hover, bob-up, sideward flight, and unattended landing) using a panel mounted CRT with various symbology sets and a helmet mounted display. The sensor measurement program obtained obstacle detection data from a variety of sensors under common test conditions for a set of obstacles ranging down to 1/8-inch field wire.

In each of these areas, quantitative data are presented along with conclusions based on the effectivity of the various systems tested. The report concludes with a recommended "core" hardware configuration required for various Army aircraft to achieve LLNO capability.

8. Wright, R., & Pauley, W. Survey of factors influencing Army low level navigation (Hum RRO-TR-71-10). Alexandria, VA: Human Resources Research Organization, June 1971.

Factors that influence low level navigation and affect Army capability in conducting low level missions were surveyed. The nature of improvements in equipment, procedures, and training needed to provide the Army with effective operational capability in low level navigation were indicated. Major conclusions from the survey: Limit capability in low level aerial navigation would have significant consequences on future Army combat effectiveness; the rapid reaction mission over unfamiliar terrain presents a low level navigation problem; no potential improvements in training or procedures for present navigation system and equipment appear capable of significantly improving low level performance; a simple automatic dead reckoning navigation computer appears to be essential to routine attainment of operationally effective low level navigation performance; reorienting navigation procedures and training to simplified Line of Position navigation techniques would improve performance with current equipment.

CHAPTER II

SYSTEM DESCRIPTIONS AND EVALUATIONS

This chapter provides literature sources on seven categories of navigation systems. It gives technical descriptions and test reports of specific navigation systems. They are:

A. Doppler
B. Inertial
C. Loran
D. Omega
E. Radar
F. Radio
G. Miscellaneous

This chapter subdivides the literature into these seven categories of navigation systems. McGrath in his work presents a table of trade-offs shown here relating the merits of the various navigation systems for Army use. The weighting factors relating cost, accuracy, and vulnerability, will determine the system best suited to mission requirements.

A. Doppler

1. Allen, R., & Starke, R. Operational test and evaluation AN/APN-31 doppler navigation system with Laboratory for Electronics map display set (TR-61-36B). Langley AFB, VA: Tactical Air Command, June 1963.

2. Brienza, D. RA5C Doppler - inertial study: Integration of the AN/APN-153(V) Doppler radar to AN/ASB-12 Bomb/Nav system (NAFI-TR-658). Indianapolis, IN: Naval Avionics Facility, September 1965. (AD380 214L)

   This report gives a brief description of the AN/ASB-12 Bomb/Nav system, its function, capability and limitation. It will present the AN/APN-153 Doppler Radar as a means of improving and/or bounding the navigational errors introduced by the AN/ASB-12. The aim of this report is to specify in detail those component and wiring changes required to integrate the two systems.

3. Buel, H. Doppler radars for low cost medium accuracy navigation. AGARD-CPP-176, September 1975.

TABLE 1

Outline of Trade-Offs Among Alternative Navigation Systems

System Type	Characteristics Relevant to Army Aviation: Favorable	Characteristics Relevant to Army Aviation: Unfavorable
• VOR Radio Beacons • TACAN • DECCA	• Low Cost • Lightweight	• Short Range • Marginal Accuracy • Vulnerable to ECM • Multiple Ground Stations • Line-of-sight Limitations
• OMEGA	• Moderate Cost • Lightweight • Worldwide Coverage	• Marginal Accuracy • Vulnerable to ECM • Vulnerable to Physical Destruction • Vulnerable to Political Shut-Down
• NAVSTAR Global Positioning System	• Highly Accurate • Worldwide Coverage	• Not Operational • Vulnerability Unknown • Cost Unknown
• LORAN C • LORAN D	• Moderate Cost • Accurate • Adequate Range	• Vulnerable to ECM • Vulnerable to Physical Destruction • Needs Calibration and Rate-Aiding
• Inertial	• Self-Contained, Secure • Passive	• High Cost, High Upkeep • Heavy Equipment • Time-Dependent Error • Needs Preflight Alignment
• Air-Data/Compass	• Low Cost • Lightweight • Self-Contained, Secure • Passive	• Inaccurate
• Doppler/Compass	• Moderate Cost • Self-Contained • Accurate Velocity	• Accuracy Depends on Compass • Needs Good MAG-VAR, Compass Swing • Propagates Signal

4. Carter, W., Jarman, R., Steele, R., & Revels, P. Operational test (OTII) of Lightweight Doppler Navigation System (LDNS) AN/ASN-128 (XE-1) Ft. Rucker, AL: U S Army Aircraft Development Test Activity, August 1977. (AD B021 014L)

The US Army Aircraft Development Test Activity conducted the Operational Test II of the AN/ASN-128(XE-1) Lightweight Doppler Navigation System during the period 21 June 1976 through 18 March 1977. Testing was conducted in the Fort Rucker, Alabama local flying area. The purpose of this test was to gather data in a realistic environment for use in assessing the military utility and operational effectiveness of the AN/ASN-128(XE-1) Lightweight Doppler Navigation System. The system was flown in UH-1H, AH1G and U-21A aircraft for a combined total of 558.3 flight test hours. An installation was made but not flown in the CH-47C. In addition, 173.0 bench operating hours were accumulated. The Pretest Inspection and Installation equipment was assessed and was found to be complete and free of defects.

5. Emtage, J. Decca Doppler 71 - Flight trials of a production version in a Wessex helicopter (TRC-BR-26143). Boscombe Down, Eng.: Aeroplane and Armament Experimental Establishment, July 1971. (AD 903 848L)

Decca Doppler 71 is the helicopter version of the Decca 70 series lightweight dopplers. A prototype equipment had previously been evaluated at A and AEE and this report covers trials of a production model. The equipment is a very satisfactory helicopter doppler, and performs well throughout the full range of maneuvers that can be expected of a rotary-winged aircraft. The doppler, which was flown for a total of 90 hours, has a high accuracy potential and exhibited good serviceability. As with some other dopplers, it can produce velocity rundowns over certain critical water conditions and, although these conditions are rare, further investigation into this characteristic is recommended.

6. Emtage, J. Flight trials of Marconi AD 510 Doppler in a Wessex helicopter (AAEE/TECH/402/NAV). Boscombe Down, Eng: Aeroplane and Armament Experimental Establishment, September 1969. (AD 892 354L)

Flight trials of a pre-production experimental Marconi AD 510 lightweight helicopter doppler were carried out at A and AEE between July 1968 and March 1969. The aircraft was flown on instrumented ranges over land and sea, and the errors from various sources have been analysed and are detailed in the body of the report. No major component failures occurred although the doppler's serviceability record was marred by minor unserviceabilities.

7. Fisher, M., Kiernan, D., Light, W., Elliott, C., & Galanti, C. Evaluation of three state-of-the-art Doppler navigation systems. (ECOM-4189). Ft. Monmouth NJ: US Army Electronics Command, January 1974. (AD 916 943L)

This report covers the flight evaluation of three state-of-the-art fixed antenna Doppler Navigation systems. Performance of the systems was tested under various conditions simulating operational usage of the Doppler in Army aircraft. Brief descriptions of the units and instrumentation are followed by a summary of test objectives and procedures used. Flight test results are given for each doppler system. Finally, navigation flight data using these units in combination with various types of heading references is presented to show an improvement in overall system performance with better quality heading sensors.

8. Gaines, H. T. Flight test of a Kalman filter doppler-aided strap-down inertial navigator. Dayton, OH: NAECON 1971, May 1971.

9. Galanti, C., & Levine, I. A doppler inertial investigation (ECOM-3247). Ft. Monmouth, NJ: US Army Electronics Command, March 1970. (AD 705 256)

An error analysis of a hybrid doppler-inertial system (second order) was performed with and without noise error sources. From this analysis it was determined that the doppler is the key contributor to the velocity error of the system. Also, a procedure for selecting the parameters of a doppler-inertial system for minimum cost and maximum performance was derived.

10. Halliwell, D. Integrated doppler/heading reference/radio navigation. AGARD-CPP-176, September 1975.

11. Kalatucka, S. Report on flight evaluation of the Ryan Electronic RYANAV IVA Doppler navigation system in a HUS-IA helicopter. Johnsville, PA: Naval Air Development Center, May 1962. (AD 447 401L)

Flight tests were performed to determine the suitability of the system for use in the Marine mission. A pictorial navigation display unit was employed to indicate the present position of the helicopter on charts such as a portion of a sectional aeronautical chart inserted in the unit. The system was operated from take-off to touchdown and indicated present position with an accuracy of approximately 2% of the distance traveled in flights over land with somewhat poorer performance over water. The system operated without a failure during the flight program.

12. Kalatucka, S. Wind and sea motion on the over water accuracy of doppler navigation sets. Phase I: Investigation of doppler navigation system performance over water in a SH-34J (HSS-IN) Helicopter (NADC-AI-6314). Johnsville, PA: Naval Air Development Center, April 1963. (AD 336 593)

Navigation and maneuvering flights over water were performed during the test program to determine over water doppler errors resulting from surface winds during such flights. The tests included the demonstration of a corrective device to improve over water performance. Reproductions of navigational and maneuvering flight plots are included.

13. Kelly, K. Lightweight integrated doppler navigation system for Army aircraft. Ft. Monmouth, NJ: US Army Electronics Laboratories, July 1960. (AD 251 255)

14. Krogmann, U. Advanced doppler-inertial navigation system for transport helicopter. AGARD Conference Proceedings 86-71, September 1971.

Due to mission requirements of Transport Helicopters in the future, use of a self-contained navigation system will be necessary. The attainable navigation accuracy should be better than 0.5% (CEP) of distance travelled. For this purpose a high-quality Doppler and attitude reference inertial platform are required. A Self-alignment capability of the attitude and heading reference platform is necessary. Here a rapid ground alignment is of particular importance.

This paper deals with different procedures for optimal use of pertinent information from the Doppler and platform to meet the self-alignment and calibration as well as navigation requirements.

Conventional ground and in-air gyrocompassing techniques together with Doppler-Inertial navigation are treated briefly. Main attention is paid to optimal ground and in-air alignment and Doppler-Inertial-Mixing. As far as the optimization is concerned, Kalman-Filter Technique with a ten to fourteen element state vector is compared to a simple digital filter-technique based on recursive or non-recursive least squares.

Comparison between the least-square-technique and the Kalman-Filter shows that their respective performance is roughly in the same order of magnitude without position fixes.

The least-square-technique is recommended because its airborne computer requirements are by far lower than the Kalman-Filter loading. This technique, as well as the Kalman-Filter has the ability to recover the position error caused by initial misalignment and the performance does not depend on the magnitude of the initial misalignment. One of the advantages of the Kalman-Filter is the ability to calibrate both the Doppler and the North-gyro if Doppler-Bias is modelable (an advantage the least-square technique does no have).

The proposed system is based on the least-square technique. Assuming a 2 - 3 minutes ground-alignment, the operational sequence for in-air alignment and Doppler-Inertial Navigation is described. The computer loading for both the ground and in-air alignment of this system is considered.

15. Lewis, R. E. F., & Anderson, D. J. Air trial of an automatic navigation system for use in low flying helicopters. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, D C : JANAIR, 1969.

Mr. Ronald E. F. Lewis and Capt. Donald J. Anderson described a series of flight trials requiring helicopter crews to navigate accurately over unfamiliar terrain while flying close to the ground throughout sorties as long as 100 miles. The purpose of the trials was to assess an automatic navigation system that consisted of a projected map display, doppler radar, and a stable-platform heading reference. Navigation by conventional methods (hand-held map) was compared to that achieved by the various modes of the automatic system. The test also compared the performances of the automatic system when updated on the basis of recognized landmarks and when operated as a free-running system.

16. McInerney, J., & Kyler, F. Operational test and evaluation of AN/APN-131 Doppler navigation system with Bendix Air Navigation Display System (TR-61-36A). Langley AFB, VA: Tactical Air Command, March 1963.

17. Miller, D., Ohlinger, J., & Taque, B. Study of doppler velocity sensors for naval aircraft (TR14). Indianapolis, IN: Naval Avionics Facility, December 1960. (AD 323 187L)

The variables involved in designing a ground speed sensor are studied in detail in order to arrive at a satisfactory compromise for light attack aircraft and anti-submarine warfare. Different types of doppler radar speed sensors are discussed with particular emphasis being placed on noise considerations, accuracy, stability, and range. Included within this report is a bibliography on doppler systems and a listing of specific military systems and their specifications. Some of the more specific topics of discussion are weather effects on radar range for K band, noise considerations for FM, CW, and pulse systems, data stabilization versus antenna stabilization, frequency tracker accuracy, and a detailed analysis of multi-beam doppler sensors. A study was also included of various tracking systems, and mathematical calculations were derived which enlighten the over-all problem of obtaining the returned doppler signal in a useable form. It was shown that approximately 5 watts per beam is needed for K band operation in a doppler system. Detailed consideration of various doppler modulation systems is shown to favor the FMCW system in regard to noise immunity.

18. Naval Air Test Center, Monitor and evaluation of the CH-46E prototype Doppler/Omega navigation system (NATC-RW-17R-74). Patuxent River, MD: Naval Air Test Center, August 1975. (AD B006 312L)

This report contains qualitative and quantitative test results concerning the CH-46E navigation system based on NAVAIRTESTCEN monitoring of laboratory, ground, and flight tests. The CH-46E navigation system operates by combining dead reckoning of self-contained velocity and heading measurements with station referenced position fixes provided by a world-wide Omega radio navigation network. The system provides a cockpit display of the present helicopter geographic position (in either latitude/longitude or Universal Transverse Mercator (UTM) coordinates), aircraft ground velocity vector (true track angle and groundspeed), and relative position vector steering information to selectable waypoints.

19. Smith, H. Doppler radar navigation system for COIN operations (RYANAV-IV Doppler Radar Navigation System). San Francisco, CA: Joint Research and Test Activity, August 1965. (AD 473 324)

An evaluation was conducted to determine the capability of a doppler radar navigation system to provide sufficiently accurate navigation data for air support operations in counterinsurgency warfare; and to determine whether the use of a doppler radar navigation system in mission aircraft contributes significantly to the successful accomplishment of the overall mission of the supported ground forces. The evaluation was conducted using the RYANAV-IV Doppler Radar Navigation System installed in both fixed (YCV-2A and U-8D) and rotary (CH-34) wing aircraft employed in the conduct of air support operations for counter insurgency warfare in the Republic of Vietnam. As a result of coupling the system to the installed aircraft gyromagnetic compass and of equipment design deficiencies, doppler system accuracy was found to be below that required for air support operations. Reliability of the test system was not adequate for sustained use under field conditions found in the Republic of Vietnam. It was concluded that the RYANAV-IV Doppler Radar Navigation System was unsuitable for use in the YCV-2A aircraft, and that the employment of doppler systems per se will not significantly improve the mission effectiveness of US Army aircraft employed in the role of air support for ground operations. Doppler radar navigation systems did contribute to the mission.

20. Steinhacker, M. Design study for VINS doppler inertial navigation system. New York, NY: Maxson Electronics Corp., January 1961. (AD 323 219)

The VINS (*Velocity-Inertial-Navigation-Systems) program objectives were* accomplished. It was demonstrated that a practical VINS system can be constructed using present day components, and that it will be applicable to all the vehicles specified. The most practical system within the state of the art was shown to be a doppler—accelerometer—full free gyro system wherein the computations for the navigational quantities are performed in terms of inertial coordinates. The performance of the system was demonstrated by employing the exact system equations. The design goal of a system delivering a 1 mph accuracy in distance, and a vertical accuracy of better than 30 sec was achieved. The design of the finally recommended system was completed to the general circuit design level, and over-all packaging layouts were prepared. While the study program has pointed up minor areas of uncertainty, the feasibility of the VINS concept was completely demonstrated.

B. INERTIAL

1. Edwards, A. The state of strapdown inertial guidance and navigation. Journal of the Institute of Navigation, 1971, 18, 386-401.

The prospect of simplifying inertial navigation systems by strapping the sensors directly to the vehicle, as commonly done in attitude control systems, has continued to intrigue investigators. Interest has persisted through the many years that have seen the gimballed, inertially stabilized platform reach maturity in military applications, in space vehicles, and recently in commercial aircraft. Motivating the interest in strapdown technology has been the belief that lower weight, lower cost and higher reliability can result if electromechanical stabilization is replaced by a computational approach which exploits advances in computer and microelectronic technology.

This paper reviews the concepts and problems underlying the strapdown approach, and covers the theoretical and hardware developments that have taken place in recent years in computers, sensors, and systems. It is noted that the initial success has been achieved in spacecraft applications where the weight saving has been important and accuracy needs have been modest. Success has led to plans for installation of systems as second generation equipment in launch vehicles where the environment is more demanding. Requirements for extending the applications are presented and Raytheon Company programs in strapdown technology that involve or are leading to road and flight test demonstrations are briefly described.

2. Fegley, K. Inertial navigation task (Rept. No. 72-07). Philadelphia, PA: Moore School of Electrical Engineering, October 1971. (AD 733 430)

The report is the final report for the task on research in the area of Inertial Navigation. The report summarizes the results of the main objectives which were to determine the feasibility of using a strapdown inertial system aboard a helicopter; to simulate systems which employ inertial elements; and to determine improved techniques to apply aided inertial navigation to Army aircraft.

3. Gaines, H. T. Flight test of a Kalman filter doppler-aided strap-down inertial navigator. Dayton, OH: NAECON 1971, May 1971.

4. Heasley, J., Bowie, C., & Carnes, F. Helicopter flight test of the AN/ASN-109 inertial navigator. Holloman AFB, NM: USAF Armament Development Test Center, April 1972. (AD 894 139L)

An AN/ASN 109 inertial navigator was flight tested in a U S Army CH-34A Choctaw helicopter. A total of 20 flights were made. These flights simulated helicopter rescue, gunship and cross country missions. Total helicopter flight time accumulated was 42.6 hours.

5. Herres, R., & Brandt, T. An analog simulation and analysis of an inertial navigation system for helicopter use. Wright-Patterson AFB, OH: Air Force Institute of Technology, March 1960. (AD 237 823)

6. King, A., Fick, M., & Sandlin, L. Aircraft navigation system verification of the Singer-Kearfott SKN-2400 (AFSWC-TR-75-45). Kirtland AFB, NM: USAF Special Weapons Center, May 1975. (AD B005 811L)

The Singer-Kearfott SKN-2400 Inertial Navigation System was tested under the Program 688G Verification Flight Test Program at the Central Inertial Guidance Test Facility, 6585th Test Group, Holloman Air Force Base, New Mexico during the period from 12 February 1973 to 20 April 1974. A total of 68 valid data tests were completed, and 764 total system operational hours were accumulated in the laboratory, cargo (NC-141A), helicopter (UH-1H), and fighter (RF-4C) aircraft testbed environments. One hundred and seventy-eight actual flight hours were logged during the test cycle, and the test systems navigated for 475 hours. Reaction time used for all tests was 20 minutes. The SKN-2400 successfully completed cargo, helicopter and fighter aircraft verification testing at the CIGTF within the meaning of applicable DOD/DDR and E directives. With respect to its performance, the SKN-2400 can be considered a one mile per hour system.

7. Krogmann, U. Advanced doppler-inertial navigation system for transport helicopter. AGARD Conference Proceedings 86-71, September 1971.

Due to mission requirements of Transport Helicopters in the future, use of a self-contained navigation system will be necessary. The attainable navigation accuracy should be better than 0.5% (CEP) of distance travelled. For this purpose a high-quality doppler and attitude reference inertial platform are required. A self-alignment capability of the attitude and heading reference platform is necessary. Here a rapid ground alignment is of particular importance.

This paper deals with different procedures for optimal use of pertinent information from the doppler and platform to meet the self-alignment and calibration as well as navigation requirements.

Conventional ground and in-air gyrocompassing techniques together with Doppler-Inertial navigation are treated briefly. Main attention is paid to optimal ground and in-air alignment and Doppler-Inertial-Mixing. As far as the optimization is concerned, Kalman-Filter Technique with a ten to fourteen element state vector is compared to a simple digital filter-technique based on recursive or non-recursive least squares.

Comparison between the least-square-technique and the Kalman-Filter shows that their respective performance is roughly in the same order of magnitude without position fixes. The least-square-technique is recommended because its airborne computer requirements are by far lower than the Kalman-Filter loading. This technique, as well as the Kalman-Filter has the ability to recover the position error caused by initial misalignment and the performance does not depend on the magnitude of the initial misalignment. One of the advantages of the Kalman-Filter is the ability to calibrate both the Doppler and the North-gyro if Doppler-Bias is modelable (an advantage the least-square technique does not have).

The proposed system is based on the least-square technique. Assuming a 2 - 3 minutes ground-alignment, the operational sequence for in-air alignment and Doppler-Inertial Navigation is described. The computer loading for both the ground and in-air alignment of this system is considered.

8. Krumm, J., Minto, D., & Ritter, W. Aircraft navigation system verification of the Litton LN-40 Inertial Navigation System. (ADTC-TR-77-66). Holloman AFB, NM: USAF Armament Development and Test Center, July 1977. (AD B022 942L)

For the test a total of 100 valid ground and flight tests were completed, and 1238 total system operating hours were accumulated. The system navigated for 617.5 hours including 201.9 hours in flight. The system was flown aboard a C-141A, an RF-4C, and a UH1H testbed. Reaction time for all valid tests varied between six and nine minutes. During the course of the test program, there were eight system chargeable failures, and five system design deficiencies (four were corrected). During cargo aircraft testing, the LN-40 performed as a 3/4 mile per hour system. During fighter aircraft testing, the LN-40 performed as a ½ mile per hour system. System performance was degraded when the platform was aligned with a west heading. The LN-40 successfully completed cargo and fighter aircraft verification testing within the meaning of applicable DOD/DDR and E directives.

9. Krumm, J., Payne, D., & Sandlin, L. Development flight testing of the N-57A inertial navigation system (ADTC-TR-75-85). Eglin AFB, FL: USAF Armament Development and Test Center, November 1975. (AD B009 155L)

The N57A-2 MESG Inertial Navigation System, a brass board predecessor of the MICRON, was tested under Program 666A, Advanced Avionics for Aircraft, at the Central Inertial Guidance Test Facility 6585th Test Group, Holloman Air Force Base, New Mexico. A total of 35 valid data tests were completed, and 393 total system test hours were accumulated in the laboratory, cargo (NC-141A), and helicopter (UH-1H) aircraft testbed environments. Total flight time was 193 hours. During the period of flight testing, the N57A-2 development system was sent back to the plant six times for various maintenance and repair actions. The N57A-2 microelectrostatic gyro system performed successfully as an aircraft inertial navigation system in the NC-141A and UH-1 airborne environments. System performance for the cargo aircraft environments was '½ nautical mile per hour' (50th percentile).

10. Messmer, J. Flight evaluation of Litton Systems, Inc. LN-3 inertial navigation systems (Rept. No. 6246). Johnsville, PA: Naval Air Development Center, May 1962. (AD 277 452L)

Flight results obtained from a Litton LN-3 Inertial Navigation System which was installed in a Navy helicopter are presented. The various flight patterns are described and vary from hover operation to that of a six-pointed star.

Velocities of the aircraft range from zero (hover operation) to 90 knots. Positional error data are presented for the flight tests and the circular probable error of the navigation system is calculated. The resultant CPE rate for four flights, each approximately two hours in duration, was 1.2 nautical miles per hour.

11. Montgomery, B., Howe, P., & Morgan, F. Integrated NAV/SAT Hybrid Inertial (INHI) flight test (AFSWC-TR-74-10). Holloman AFB, NM: Central Inertial Guidance Test Facility, May 1974. (AD 922 402L)

This report documents the development flight testing of the Integrated NAVSAT Hybrid Inertial (INHI) system in a U.S. Army UH-1H aircraft against simulated satellites located on the ground at White Sands Missile Range. The purpose of the test program was to qualitatively and quantitatively evaluate the INHI system in various modes, operating both with and without low cost inertial components. Due to the developmental nature of the test program, the contractor was give wide latitude in adjusting and changing the system between tests. The test program consisted of 25 test flights conducted from 29 August 1973 until 20 December 1973. The system was flown in three different modes, all of which primarily incorporated on 18-state Kalman filter with varying combinations of hardware. Mode I operation used only NAVSAT receiver information. Mode II used the NAVSAT receiver in combination with a Heading All-Altitude Reference System (HAARS).

12. Rosa, J. Inertial navigation system test and evaluation in an HH-53 helicopter. Scott AFB, IL: Military Airlift Command, September 1970. (AD 875 910L)

MAC Test 13-2-70 was conducted to evaluate Inertial Navigation System (INS) potential applications in Aerospace Rescue and Recovery Helicopters to enhance rescue capabilities, particularly during hours of darkness. It was concluded that an INS can provide an increased capability for accurate en route navigation to the rescue area. It was recommended that consideration should be given to an INS as an en route navigation aid for any proposed full night recovery helicopter system. Additionally, the ground speed readouts of the INS should be capable displays of miles and tenths of miles between 0 and plus or minus 10 knots and minutes and tenths of minutes of time to go to destination. Further, the INS alignment time should be reduced so that immediate launches will not be delayed for INS alignment.

13. Steinhacker, M. Design study for VINS Doppler inertial navigation system. New York : Maxson Electronics Corp., January 1961. (AD 323 219)

The VINS (Velocity-Inertial-Navigation-Systems) program objectives were accomplished. It was demonstrated that a practical VINS system can be constructed using present day components, and that it will be applicable to all the vehicles specified. The most practical system within the state of the art was shown to be a doppler-accelerometer-full free gyro system wherein the computations for the navigational quantities are performed in terms of inertial coordinates. The performance of the system was demonstrated by employing the exact system equations. The design goal of a system delivering a 1 mph accuracy in distance, and a vertical accuracy of better than 30 sec was achieved. The design of the finally recommended system was completed to the general circuit design level, and over-all packaging layouts were prepared. While the study programs has pointed up minor areas of uncertainty, the feasibility of the VINS concept was completely demonstrated.

14. Taylor, G. R., Donaghy, J. F., & Putnam, B. G. Field tests of a developmental strapdown system. Fifth Biannual Guidance Test Symposium, Holloman AFB, NM, October 1970.

C. LORAN

1. DeLorme, J. F., & Tuppen, A. R. Low cost navigation processing for LORAN-C and Omega. AGARD-CPP-176, September 1975.

2. Frank, R. L. Current developments in LORAN-D. Journal of the Institute of Navigation, 1974, 21, 234-241.

Loran-D is a highly accurate pulsed hyperbolic navigation system similar to and compatible with Loran-C, but designed for military tactical use. The helicopter—transportable—transmitter stations have quickly erectable antennas using new tower technology. A signal range over half that of Loran-C is achieved by the fortunate propagation characteristics of 100 KHz waves, by a modified compatible signal format and by improved transmitter solid state technology. Deployments of the stations in the US and Europe are described. The potential uses of Loran-D include: gap filler in Loran-C coverage, a transportable survey system, and long range navigation coverage for many civilian applications.

3. Hughes, M., & Adams, R. An operational flight test evaluation of a Loran-C navigator (USCG-9-77). Palo Alto, CA: Systems Control, Inc., March 1977. (AD A039 498)

This report presents the results of an operational test and evaluation of a Loran-C navigation system. The tests were performed in a Coast Guard HH-52A helicopter from 21 September to 19 October 1976. The flight test profiles, procedures and test objectives were developed to determine the applicability of the prototype Loran-C navigator to Coast Guard operations as well as to assess the functional and accuracy performance of the Loran-C navigator operating as an area navigation system in the national Airspace System. The operational testing reported in this document includes search and rescue missions as well as surveillance and enforcement missions. The former consisted of evaluating the Loran-C navigator during creeping line, sector, and expanding square search patterns. The latter involved performing low altitude hovers over fixed and movable objects and documenting Loran-C accuracy and repeatability. This latter data is also directly applicable to the operations of the off-shore oil industry.

4. Litton Industries. U.S. Army flight test Litcom Loran/UTM navigation set LRN-101 (LWL-CR-02P70). Melville, NY: Litton Industries Litcom Division, October 1970. (AD 877 818L)

The LITCOM Loran/UTM Navigation Set, LRN-101, was flight tested aboard an UH-1D helicopter. The primary function of the navigation set is to provide position location information to the pilot/navigator in UTM coordinates. Sixteen UTM grid squares are stored in the Navigation Set. In addition, the system provides navigation information consisting of range, bearing course deviation and track distance-to-go to any of 10 front panel insertable targets. A total of 49.5 hours of flight test data were accumulated. Analysis of these data shows the system capable of providing position location information to an accuracy of 50-100 meters and to be suitable for use in helicopters. Additionally, the LRN-101 was shown to be capable of fulfilling the Army's basic airborne navigation requirements in areas with Loran C coverage.

5. Matthews, C. Investigative effort to determine Loran C applicability to tactical warfare. Part I (TR-69-08). Arlington, VA: International Engineering Co., July 1969. (AD 857 597L)

Under Navy Contract Number N00019-69-C-0379, International Engineering Company undertook the task of determining applicability of retransmitted Loran C/D to guidance of the QH-50 DASH helicopter. Results of the experiment show that the standard AN/AKT-20 transmitter and the AN/SKR-1 receiver are capable of providing Loran C/D telemetry with essentially no degradation. Further, recovered remote position precision was demonstrated to be identical to precision obtained by direct reception and normal processing in a Loran C/D receiver. As with conventional processing, precision is limited by receiver resolution and Loran C/D signal-to-atmospheric noise and interference ratio.

6. Matthews, C. Investigative effort to determine Loran C applicability to tactical warfare. Part 2 (TR-69-08-PT-2). Arlington, VA: International Engineering Co., July 1970. (AD 871 367L)

This report constitutes part two of the final technical report. Results, herein reported, show the standard AN/AKT-20 and AN/SKR-1 may be employed for Loran C/D retransmission concurrent with normal QH-50 telementry. Data supports the conclusion that retransmitted data recovery is within the resolution of the receiver utilized for data processing.

D. OMEGA

1. Brogden, J., Duckworth, A., & O'Neill, J. Rendezvous accuracy of the Omega navigation system (NRL-1573). Washington, DC: Naval Research Laboratory, November 1964. (AD 453 921)

Omega is a long-range, very-low-frequency radio navigation system with capabilities of providing a fix with a certainty y of one mile or less at ranges of 5000 miles from the transmitting stations. The variations in propagation velocitiesof the signals over a particular path are the major cause of the errors. If the system is used as a rendezvous aid, the propagation errors will cancel out. Thus, the rendezvous accuracy will be greater than the absolute accuracy. The object of this investigation was to determine the rendezvous accuracy of a helicopter and a truck in various surroundings by use of Omega. The Forestport-Summit transmissions demonstrate that the system could be used as a rendezvous aid with accuracies of around 200 yards, with the time of day or environment having no apparent effect on the rendezvous errors. The Haiku-Summit pair showed a greater variation in rendezvous error. In past experiences with the Mark I receiver if the automatic gain control (AGC) meter indicated more than 40 microamperes, the signal input amplitude was marginal. During this experiment the majority of the AGC readings were above this value for receptions from Haiku. The additional electrical noise in the helicopter and an inadequate antenna combined with the already weak Haiku signal aided in making the Haiku-Summit readings marginal.

2. DeLorme, J. F., & Tuppen, A. R. Low cost navigation processing for LORAN-C and Omega AGARD-CPP-176, September 1975.

3. Naval Air Test Center. Monitor and evaluation of the CH-46E prototype Doppler/Omega navigation system (NARC-RW-17R-74). Patuxent River, MD: Naval Air Test Center, August 1975. (AD B006 312L)

This report contains qualitative and quantitative test results concerning the CH46E navigation system based on NAVAIRTESTCEN monitoring of laboratory, ground, and flight tests. The CH-46E navigation system operates by combining dead reckoning of self-contained velocity and heading measurements with station referenced position fixes provided by a world-wide Omega radio navigation network. The system provides a cockpit display of the present helicopter geographic position (in either latitude/longitude or Universal Transverse Mercator (UTM) coordinates), aircraft ground velocity vector (true track angle and groundspeed), and relative position vector steering information to selectable waypoints.

4. Sakran, F. Final report: Technical evaluation of advanced development model of airborne Omega navigation set (Rept. No WST-25R-71). Patuxent River, MD: Naval Air Test Center, March 1971.

5. Sakran, F. C., & Burch, P. B. Flight tests of two Omega navigation systems. Journal of the Institute of Navigation, 1974, 21, 194-207.

Two current Omega navigation systems designed for airborne use have received military designations: the AN/ARN-99(V)2 and the AN/ARN-115. Both use general purpose digital computers to provide fully automatic synchronization, phase tracking, station selection, and diurnal propagation corrections for display of aircraft latitude/longitude position coordinates. Both systems use all three Omega navigational frequencies, but only the ARN-99(V)2 implements difference frequency lane resolution. The ARN-115 employs three station hyperbolic geometry to directly determine geographic position. The ARN-99(V)2 estimates position by statistically optimum weighting of all available Omega measurements in a Kalman filter algorithm. The U.S. Naval Air Test Center recently evaluated both systems during flight tests in P-3 type aircraft. Observed accuracy of the two mechanizations is presented with emphasis on the effects of station geometry and diurnal propagation correction errors. Experiences with sudden station outages, precipitation static an on-board generated coherent interference are discussed.

E. RADAR

1. Braid, J. M. Radar/map matching in navigation and attack. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. James M. Braid discussed techniques and equipment for radar/map matching, and showed how they are cost-effective in modern navigation and attack systems. Mr. Braid's main message was that the advantages of radar/map matching can be obtained with negligible penalties by recognizing the advantages conferred by modern moving-map displays coupled to the more accurate navigation systems now available and by avoiding the misconception of believing that absolutely distortion-free map and radar images must be produced for accurate updating.

2. Dunkel, H. Airborne radar for helicopter navigation (FAA-RD-66-74). Atlantic City, NJ: National Aviation Facilities Experimental Center, September 1966. (AD 649 767)

A Ground Mapping Airborne Navigation Radar BHR-3 was developed. The radar system, operating in the 15.4 to 15.7 gc (Ku-band) was tested to provide data on the feasibility and usefulness of the system for helicopter navigation and to examine the suitability of radar enhancement devices. Additional tests planned to determine the effects of pilot fatigue and learning, aircraft altitude and limiting minimums of operation, and BHR-3 range scales on navigation with the ground mapping radar were canceled due to the unacceptable system performance observed during the initial tests. Tests were performed with the BHR-3 system installed in an S-61L Helicopter leased from Los Angeles Airways.

3. Emery, J. H. High-resolution, ground-mapping radars as an orientation aid in helicopter flight. In J. J. McGrath (Ed), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. J. H. Emery reported a field trial conducted as a part of the development program of a radar system for helicopters. To determine the feasibility of the system as a cockpit display, experienced test pilots conducted a series of flight tests involving point-to-point navigation, terminal area maneuvering, and the approach to landing. Geographic orientation was the primary task in the cross-country flights and was essential for successful execution of the terminal area runs. The results were discussed in terms of the pilots' capabilities for navigating by the radar to perform ground-referenced maneuvers. Recommendations were offered for improving this capability by the development of special-purpose radar maps.

4. Jerrell, J. Lightweight ASW helicopter radar (Rept. No. TR46). Indianapolis, IN: Naval Avionics Facility, February 1961. (AD 255 218)

The use of rotary wing aircraft in modern ASW operation has created the need for a lightweight, reliable electronic system, capable of providing collison avoidance and station keeping information. This information is required to allow effective operation at night and in all weather conditions, as well as to enhance safety in daylight operation.

Present investigation concerns air frame compatibility, which includes a study of a combination rf and hydraulic rotary joint, rerouting of hydraulic and electric lines, relocation of components and structures within the rotary wing drive shaft, mounting of the antenna atop the shaft, and general system integration. Additional studies concerning the form of the electronics were developed. Careful consideration indicates that a combined radarbeacon system is most feasible, since the capabilities and advantages of both will provide maximum information for safe operation of the ASW aircraft. A functional description of the system with pertinent details is included.

5. Jerrell, J. Radar set AN/APQ-95 (XAN-1) (HELCAR) (NAFI-TR-239). Indianapolis, IN: Naval Avionics Facility, December 1963. (AD 436 846)

This report describes, in general terms, the results of the research model development and flight feasibility testing of the AN/APQ-95 (XAN-1) radar-beacon system. Also included are recommendations concerning performance and configuration requirements of a production version of the equipment. This is an interim publication and will be followed by a Final Hardware Development Report which will provide extensive details concerning AN/APQ-95 (XAN-1) development.

6. Naval Air Test Center. Technical evaluation of the AN/APN-182 (V) radar navigation set installed in the CH-46A helicopter (NATC-WST-31R-73). Patuxent River, MD: Naval Air Test Center, February 1973. (AD 908 166L)

The purpose of this test was to install the AN/APN-182(V) Radar Navigation Set in the CH-46A helicopter, to perform a technical evaluation which includes electrical inspection, navigation accuracy and sensitivity, and electromagnetic compatibility (EMC), and to determine service suitability of the system. This report delineates the results of the technical evaluation. Service suitability test results will be reported in the Second Interim Report. The Final Report will discuss installation of a modified doppler radar support kit and EMC of equipment peculiar to the second aircraft.

7. Naval Air Test Center. Technical evaluation of the AN/APN-182(V) radar navigation set installed in the CH-46A helicopter (NATC-ST-59R-73). Patuxent River, MD: Naval Air Test Center, April 1973. (AD 909 736L)

The CH-46A helicopter with the AN/APN-182(V) Radar navigation set (doppler) installed was evaluated for the day and night search and rescue (SAR) mission.

8. Naval Air Test Center. Technical evaluation of the AN/APN-182(V) radar navigation set installed in the CH-46A helicopter (NATC-WST-14R-74). Patuxent River, MD: Naval Air Test Center, February 1974. (AD 917 207L)

The purpose of this test was to evaluate the installation of the AN/APN-182(V) Radar Navigation system in the CH-46A helicopter. This report discusses the evaluation of the modified Airframe Change kit installed in the second SAR helicopter, CH-46A BuNo 150947. Electromagnetic Compatibility (EMC) of the AN/APN-182 with the AN/ARC-131 communications radio was also evaluated. THE ID-1932 Ground Speed-Drift Angle Indicator was evaluated as a potential future replacement for the ID-862 Ground Speed-Drift Angle Indicator presently used with AN/APN-182 systems.

9. Palmquist, M. Helicopter radar navigation system and enhancement devices. Hollywood, CA: Bendix Corp. Bendix-Pacific Division, September 1964. (AD 612 610)

The radar system developed for this program operates in the 15.4 to 15.7 gc navigation band, and uses a slotted array antenna to form an approximate cosecant squared pattern. The direct-view storage display unit provides a bright PPI display, with range representations of 1.5, 5.0, and 15.0 miles. Information renewal rotation speed is 30 rpm; pulse length is 0.22 microseconds and beam width is two degrees. Selection of video types is incorporated to enable evaluation of the FTC, video processor, and displaying beacons. The scope of the program was expanded to include three compatible ground-based beacons, and three passive enhancement devices.

10. Ryan Aeronautical Company. Navigation set, Radar AN/APN-130 (XN-1) (Rept. No. 10163-1). San Diego, CA: Ryan Aeronautical Co., August 1960. (AD 248 196)

F. RADIO

1. Bauss, W. Radio navigation systems for aviation and maritime use: A comparative study. New York: MacMillan Co., 1963

This report represents the work of a joint committee formed for the purpose of examining and comparing the present long and medium-range navigation systems, applying uniform rules of evaluation. It was intended to analyse the extent to which the systems are suitable for common use by civil aviation and merchant marine. To complete this task, it has become apparent that it was necessary to base such a comparison on a common basis. Several tables were compiled presenting a survey of the problems treated.

2. Bourne, I., & Segal, B. An investigation into some problems associated with the use of the Decca 'Hi-Fix' navigation system in the Canadian Arctic (DRTE-1196). Ottawa, Ontario: Defense Research Telecommunications Establishment, July 1968. (AD 840 675)

Serious difficulties were encountered in the operation of a 1.71 MHz phase comparison radio navigation system in the waters of the Canadian Arctic. Measurements of propagation conditions showed that the useful range of such a system can be severely restricted by the presence of an ice cover. This led to a theoretical investigation of radio wave propagation over a stratified ice-water surface. Whereas a homogeneous medium with plane boundary always displays a resistive or only slightly inductive surface impedance, a rough or stratified medium may, under certain cirucumstances, exhibit a highly inductive surface impedance. Over such a surface the ground wave, as exemplified by the Sommerfeld attenuation function, may vary strongly and rapidly with distance, both in amplitude and in phase. It is found that for physically realizable ice-covered surfaces the ground wave field intensity at a finite distance from a transmitter may be reduced to zero and that the phase velocity of the wave at that range may become infinite.

3. Dean, S. Wessex HAS Mark 3 tropical trials assessment of the navigation and radio equipment (AAEE/931/3-Pt-7). Boscombe Down, Eng.: Aeroplane and Armament Experimental Establishment, February 1968. (AD 839 256L)

This report covers the ground and flight testing of the radio installations on Wessex XM 919 in the hot weather environment at El Centro, USA.

4. Dutton, E. Initial production test of the AN/ARN-82 omni-range radio receiving set. Ft. Rucker, AL: US Army Aviation Test Board, March 1966. (AD A031 193)

The USAAVNTBD conducted the Initial Production Test of the AN/ARN-82 Omni-Range Receiving Set in the vicinity of Fort Rucker, Alabama, from 3 January to 23 February 1966. The sets were installed in a U-8D Airplane and a UH-1D Helicopter and were operated in flight for 54 hours. The general concept of the test was to verify adequacy and quality of the production AN/ARN-82 by performing the same operational and flight tests on the AN/ARN-82 as those conducted on the off-the-shelf omni-range receiver. Additional tests were conducted to determine whether the deficiencies and shortcomings reported on the off-the-shelf set had been corrected. The installation characteristics were adequate and were the same as those of the previously tested off-the-shelf equipment. Maintenance and support requirements reported for the off-the-shelf set remained unchanged. Three of the six deficiencies remained unchanged. Three of the six deficiencies previously reported were satisfactorily corrected. Internal lighting of the course indicator and two modifications to the control panel were not provided as previously recommended. No new deficiencies were discovered. One additional shortcoming was noted.

5. Quinn, G. A comparison of air radio navigation systems (for helicopters in off-shore areas) (FAA-RD-76-146). Washington, DC: Federal Aviation Administration, August 1976. (ADA030 337)

This paper examines the technical potential of ten navigation systems that may meet specific IFR en route navigation requirements for helicopters operating in off-shore areas. Technical factors considered essential for navigation are: (1) operational range, (2) operation altitude, (3) accuracy, and (4) reliability. Not addressed in this paper are such operational factors as pilot workload, number of way points, type of display, etc. Estimated user equipment cost will be included because of its importance in system selection.

G. COMPARISONS, MISCELLANEOUS UNKNOWNS

1. Adams, A., Cameron, J., & Sakran, F. Flight test of six navigation systems in the CH-46F helicopter (NATC-WST-120R-71). Patuxent River, MD: Naval Air Test Center, August 1971. (AD 886 911L)

The test was conducted to determine the feasibility of using current off-the-shelf navigation systems to satisfy the requirements of Marine assault helicopters and to provide data for the use of the Naval Air Systems Command in determining the best systems approach to meet the future Marine Corps helicopter/VSTOL navigation requirements. Although all the systems evaluated are compatible with the helicopter environment, none provided the navigation accuracy required.

2. Advisory Group for Aerospace Research and Development. Helicopter guidance and control systems. Paris France: AGARD-CP 86-71, September 1971. (AD 731 670)

Contents: Military helicopter requirements; low speed control to landing on instruments in helicopters; an optimum military helicopter navigation system; automatic flight control system for light helicopters; an integrated low altitude flight control system for helicopters; subsystems; advanced development; test results and operational experience.

3. Aerospace Corporation. Design concept for the defense navigation satellite system. El Segundo, CA: Aerospace Corp., July 1972. (AD 524 329L)

The USAF has proposed a Defense Navigation Satellite System, System 621B, employing satellites in 24-hour orbits which transmit synchronized ranging signals and ephemeris information to ground, sea, and airborne users, on a continuous, global basis. A regional developmental system has also been proposed. With either configuration, the system will supply extremely accurate three-dimensional position and velocity fixes to appropriately equipped users in the region covered and will satisfy the navigation requirements, of a wide spectrum of users. The applications, requirements, design fundamentals and baseline design for both the developmental and operational systems are presented, along with the System 621B development history.

4. Atlantic Fleet Operational Development Force. Evaluation of low-altitude navigation equipment (LANE) (Project Report 28-OP/V132/X24). Atlantic Fleet Operational Development Force, 1963.

5. Dinter, E. Seat test demonstration of ITNS/ISCS-II aboard the USS Guam (NADC-74211-60). Warminster, PA: Naval Air Development Center, December 1974. (AD C001 026L)

This report describes a tactical demonstration of a relative navigation system. The equipment was operated by the normal crew of operational squadron HS-15. The results showed an improvement in both the tactics and the command functions of the ISCS (Interim Sea Control Ship) from which the ITNS (Integrated Tactical Navigation System)-equipped helicopters operated.

6. Naval Air Test Center. Pre-evaluation preproduction monitor and Navy preliminary evaluation of the CH-46E aircraft (NATC-WST-140R-74). Patuxent River, MD: Naval Air Test Center, November 1974. (AD B000 394L)

NAVAIRTESTCEN has recently monitored the Boeing Vertol Corporation compass compensation procedures and other ground checks involving operation of the A24G-39 Attitude Heading Reference System (AHRS), and has conducted the first in a series of Electrical Inspections. The purpose of the tests performed at the Boeing Vertol Company facilities in Philadelphia, Pennsylvania was to provide the Naval Air Systems Command (NAVAIRSYSCOM) with early reports of deficiencies and recommended corrective action.

7. Naval Air Test Center. SH-3H TACNAV prototype evaluation (NATC-WST-11R-75). Patuxent River, MD: Naval Air Test Center, March 1975. (AD B003 371L)

The prototype Tactical Navigation System (TACNAV) is an Integrated Tactical Navigation and Display System designed for use in the SH-3H helicopter. The TACNAV system will replace the present AN/AYK-2 Analog Navigation Computer and PT-434A Servo Driven Plotter.

8. Shramko, B. Model SH-3A helicopter feasability investigation and technical evaluation of a helicopter integrated ASW/Marine assault integrated tactical navigation and display system. Patuxent River, MD: Naval Air Test Center, September 1964. (AD 447 485)

The feasibility investigation and technical evaluation of the PHI-201B Helicopter Navigation System was conducted to ascertain the feasibility of a combined tactical system, and to test and evaluate the combined Integrator Tactical Navigation and Display System for possible use in Navy ASW and Marine assault helicopters. The operation of the PHI-201B navigation system was superior to existing navigation systems in accomplishment of the ASW mission. The PHI-201B basic navigation system provides an effective solution for the Marine Assault Mission. Incorporation of recommended equipment modifications is required for increased system performance in accomplishment of the Navy ASW and Marine Assault Mission.

9. Sperry Gyroscope Company. Navigation set, aircraft AN/APN-118(). Great Neck, NY: Sperry Gyroscope Co. March 1961. (AD 261 280)

10. Stevenson, G. Combat air vehicle navigation and vision (CAVNAV) (LWL-TR-74-36). Aberdeen Proving Ground, MD: Army Land Warfare Laboratory, December 1973. (AD 918 827L)

The CAVNAV program was designed to test the feasibility of three approaches/techniques for flying helicopters at low levels at night. All approaches are based on giving the pilot as near as possible the equivalent of his daylight vision. The first approach was to equip the helicopter with search lights that provide sufficient visible illumination around the aircraft. The second approach was to equip the pilot with night vision goggles AN/PVS-5. The third approach was to use infrared searchlights and pilots wearing night vision goggles. The program determined that the goggles were the best approach for tactical employment.

11. Sturdivant, K. Terrain contour matching (TERCOM) navigation system. In Proceedings of a Symposium on Staying Power. Ft. Rucker, AL: US Army Aviation Center, July 1975.

12. *Tactical Air Reconnaissance Center. Evaluation of improved* RF-101 navigation system (Test-65-39). Langley AFB, VA: Tactical Air Command, August 1966.

CHAPTER III

NAVIGATION DISPLAYS

There exists three basic ways to present navigation information to the aircrew. They are digital, symbolic, and pictorial displays. These display techniques are not necessarily mutually exclusive. Some navigation displays provide two or more of the techniques in a given display.

The digital display technique provides the aircrew with a digital readout of present position in appropriate coordinates. It is not very helpful unless this information can be readily translated to a position on a map. Workload and errors may preclude the utility of this technique for Army operations.

Symbolic displays are usually identified as Horizontal Situation Indicators (HSI). This display technique also requires the transposition of flight path, vector, and heading of a digital position information to a map. The error and workload issues related to digital displays apply here. In addition, the HSI displays do not afford a method for updating a navigation system.

Pictorial displays can be classified in four categories. These are direct-view map displays, combined map/CRT displays, projected map displays, and electronically-generated map displays.

Direct View map displays have the follwoing advantages and limitations:

<u>Advantages</u>
Can be used with standard paper maps
Cartographic support is readily available
Aircrew has direct access to the map
Map annotation is possible
Lightweight
Portable
Comparatively inexpensive
Pentracing of track is possible

<u>Limitations</u>
Small map storage capacity
Normally a limited operating range on the display
Direction of map orientation is fixed
Heading and steering information cannot be readily shown

The advantages and limitations to combined map/CRT displays are listed below:

<u>Advantages</u>
CRT versatility
Information can be selected, amended, updated
Dynamic movement, intensification, and blinking of symbology can be employed
Limited map annotation possible
Real-time or predictive information can be presented

<u>Limitations</u>
Complex systems
Large, heavy, and costly
Potential legibility problems
Increased computer capacity required

Projected map displays exhibits the following advantages and limitations.

Advantages
Large cartographic area
Selectable map scales
Selectable track-up or north-up orientation
Steering information readily integrated

Limitations
Limited map annotation possible
Flight path not normally portrayed
Specialized microcharts needed

The relative advantages of limitations of Electronic Map Displays are described below:

Advantages
Computer/display versatility
Time sharing of display possible
Selective, as needed, information
High reliability
Flexible display characteristics

Limitations
Cost
Potentially large computer capacity

The literature listed in this chapter and Chapter II amplifies the relative merits of these display techniques.

1. Brown, A. The use of pictorial displays for navigation. Paper presented at the 13th Technical Conference of the International Air Transport Association, Lucerne, Switzerland, May 1960.

2. Carel, W. Pictorial displays for flight (TR-2732. 01/40). Culver City CA: Hughes Aircraft Co. December 1965.

This is the final report of a study to examine the potential of raster scan pictorial displays for aircraft applications. The scope of the study was restricted to four mission segments: 1) Take-off, 2) Climb-out, 3) Point to point navigation and 4) Landing. The program was divided into two phases: the analysis of the potential of pictorial displays, and the definition of the associated sensor and data processing requirements.

3. Curtin, J., Emery, J., & Elam C. Flight evaluation of the contact analog pictorial display system. Ft. Worth, TX: Bell Helicopter Co., February 1966. (AD 640 597)

The work represents a series of flight test evaluations of a vertical flight display or contact analog. Three experimental flight tests were conducted in the JANAIR flight test vehicle which was a UH-1 helicopter known as Research Helicopter Number 2 (RH-2). The first study evaluated the vertical display containing the basic grid plane plus a ground position indicator. The hover flight mode was the test maneuver. Four types of control stabilization were tested with the display with varying degrees of control sensitivity. The second study examined the basic grid plane with and without a director symbol in the form of a flight pathway. Speed indices were presented on the pathway in the form of tarstrips and speed markers. During cross-country flight maneuvering, a ground position indicator defined final touch-down position. Only one flight stabilization mode was tested. The flights were comprehensive in their coverage of the spectrum of basic flight maneuvers. The final investigation was designed to determine the usefulness of augmenting the display components (horizon line and basic grid plane) with a TV presentation superimposed upon the vertical flight display. Several flight modes were investigated.

4. Dougherty, D., & Emery, J. Contact analog simulator evaluations: Vertical display with horizontal map display (Rept. No. D228-421-020). Ft. Worth, TX: Bell Helicopter Co. October 1964.

5. Dure, J. D. Implementation of combined display requirements. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. John D. Dure presented the results of an operations analysis, supported by breadboard investigation, to determine the requirements for combined displays. The display functions and the display requirements for navigation, flight control, and sensors were reviewed. Mr. Dure suggested a cockpit display configuration to meet the requirements. In addition, he identified the current trends in operational systems and in display methods for the short-term, medium-term, and long-term time scales.

6. Fedderson, W. Experimental evaluation of an eight-inch CRT contact analog presentation. Ft. Worth, TX: Bell Helicopter Co., May 1962. (AD 294 781)

A summary is presented of the work undertaken to determine the effect upon performance of a change in geometric perspective of ground plane information as introduced by a reduction in the physical size of a contact analog display. This study was necessitated by the introduction of a 'compression' factor which is associated with a reduction in display size when achieved with projection or closed circuit TV systems. Since this compression factor represents a departure from real-world coincidence, it was necessary to determine its effect upon hovering performance when compared with the Autonetics display in which the compression factor was not present. The results indicate that the differences in performance on the two displays were not significant and that rather gross changes could be made in ground plane perspective without affecting performance. Although the limits of such allowable changes have not been established, it would appear that as long as the perceptual relationship between the generated ground plane and the earth's surface is analogous, then the limits of such changes might be quite broad.

7. Heininger, H. G. Computer-managed integrated controls and displays for airborne operations. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. Howard G. Heininger presented a concept of cockpit instrumentation that capitalizes on modern methods of digital processing and data formatting, the use of multi-purpose and multi-sensor CRT and solid-state displays, and the design of integrated crew-station control panels. Within this context, Mr. Heininger advised, the advantages of computer-managed integrated controls and displays are reduction in weight, power, space, cost, and complexity; improved reliability and flexibility; improved systems management; and the capability to handle the large amounts of data and sensor information that must be displayed to crew members.

8. Ketchel, J., & Jenney, L. Electronic and optically generated aircraft displays: A study of standardization requirements (JANAIR-680505). Washington, DC: Office of Naval Research, May 1968.

This study reviewed and analyzed the research literature relating to electronically and optically generated aircraft displays. The purpose was to provide background information to support standardization of such displays for military aircraft. The scope of the inquiry was limited to vertical and horizontal situation displays, either of the direct view or projected (head-up) type, used by the pilot for aircraft and mission control. The results have been set forth under three major headings:

1) Information Requirements - a synthesis of 16 system studies and 11 current display designs to determine the basic information content necessary for general flight and certain special missions.

2) Symbology - an evaluation of research findings dealing with static and dynamic symbol characteristics and display format.

3) Display Characteristics - a delineation of optimum visual characteristics of displays in relation of the conditions of use and the techniques of image generation.

The report also contains an extensive bibliography and specific recommendations for additional research.

9. Pelton, F. M. An analytical investigation of low altitude display systems (LADS) (CAL-IH-2116-B-1). Buffalo, NY: Cornell Aeronautical Laboratory, October 1968. (AD 502 760)

An analytical study was conducted using the systems approach to derive avionics systems concepts and display configurations which potentially offer improved low altitude flight capabilities. Primary consideration was given to obtaining information pertinent to the design of terrain following (TF), terrain avoidance (TA), and navigation (NAV) display systems for use in all classes of single-place tactical air-vehicles during the low altitude penetration phase of preplanned missions. A review of operational requirements and existing capabilities indicated that a major advance in mission effectiveness is dependent on obtaining improved nav capabilities.

10. Roscoe, S. N. Navigation displays for the 1970's. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Dr. Stanely N. Roscoe presented a general discussion of area navigation computing and display for the air traffic system of the 1970's. The implications of recent FAA decisions concerning area navigation requirements were discussed, and the concept of volumetric air traffic control was defined. Dr. Roscoe summarized the main functional requirements of airborne systems capable of area navigation, vertical guidance, and speed control. He then reviewed the main functional requirements of airborne systems capable of displaying navigation information and specified criteria for evaluating such systems. The features, advantages, and disadvantages of symbolic displays, pictorial displays, and combined pictorial-symbolic displays were compared. A display system meeting the criteria for volumetric air traffic control was defined.

11. Ruffell Smith, H. P. The development of pictorial displays for air navigation. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Dr. H. P. Ruffell Smith traced the history of the development of map displays for air navigation, emphasizing primarily the displays developed by the Decca Navigator Company. The pilotage problems that result in the need for automated map displays were reviewed and the tradeoffs between direct-view map displays and projected map displays were summarized. Dr. Ruffell Smith also reviewed the main design problems encountered in the development of map displays and presented many examples of the specialized charting that has been produced for such displays.

12. Tsoubanos, C., & Covington, R. Preflight test simulation of superimposed trajectory error displays (ECOM-4184). Ft. Monmouth, NJ: US Army Electronics Command, January 1974. (AD 773 823)

The report describes a man-machine simulation of an image display (TV video terrain image) enhanced by the superposition of symbology conveying quantitative information. A hierarchy of symbolic displays with increasing information content superimposed on a TV video terrain image is developed as an aid in approach and in precision hover. The most sophisticated configuration required ground position information. To obtain ground position information, a position sensor which utilized a ground beacon radio such as the Electronic Location Finder (ELF) was simulated. The position information was shown to be necessary to obtain hover precision of less than five feet. Aircraft stabilization equipment (ASE) was also found necessary.

13. Wright, R. H., & Waller, T. G., Pictorial navigation displays and low altitude navigation. Fort Rucker, AL: US Army Aviation Human Research Unit, Consulting Report, April 1964.

In September 1962, personnel from Task LOWENTRY of the U.S. Army Aviation Human Research Unit participated in an evaluation of a pictorial navigation display conducted by the U.S. Army Aviation Test Board. The display which was evaluated at that time was the RT-1B Pictorial Navigation Display, manufactured by the Electronics Division of American Car and Foundry (ACF). The display was designed primarily for airways navigation and instrument approaches. Though it is not suitable for tactical Army aviation use in its present mode, it was examined in order to evaluate the display concept, to determine capabilities and limitations of pictorial displays, and to gain information on techniques which would facilitate operational use of such displays.

CHAPTER IV

MAPS AND MAP DISPLAYS

The literature in this chapter covers the issues related to maps along with specialized cartographic issues related to map and chart development. The chapter is divided into two broad areas:

A. Maps and Charts

B. Map Displays

1. General
2. Display characteristics and descriptions
3. Moving map displays
4. Projected map displays
5. Roller map displays

The literature in this chapter is organized in the format described above. The literature on map displays amplifies the literature of Chapter III.

A. MAPS AND CHARTS

1. Bard, R. R. Pilot disorientation and associated cartographic solutions. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. Robert R. Bard presented a general review of the reasons for pilot disorientation attributable to the design and the limitations of aeronautical charts and navigation display devices. The role of cockpit map displays in preventing disorientation was briefly reviewed.

2. Borden, G. Training pilots in the use of aeronautical charts: A conference report (Tech. Rep. 751-15). Goleta, CA: Human Factors Research, January 1968.

This report describes the results of a conference that was held to establish guidlines for improving the training of pilots and navigators in basic map-reading skills. A review of present training syllabi indicated that pilots presently acquire map-reading skills through "on-the-job" experience because very little formal training is devoted to it. It was concluded that the main aspect of map reading that requires more effective training is visual referencing, that is, the pilot's ability to relate the topographic features of the chart to their counterparts in the real world.

The following recommendations were made to improve map-reading training:

1. A chart users manual should be produced and distributed to training commands to explain those aspects of chart design and production which influence the fidelity with which the earth can be portrayed and which may influence the pilot's ability to navigate by visual pilotage.

2. Motion pictures showing the view of the terrain from low-flying aircraft should be produced and distributed to training squadrons. These films would serve to introduce pilots to the techniques of visual pilotage in low-altitude flight.

3. A feasibility study should be conducted to determine the utility of dynamic visual flight simulators for training map-reading and other visual navigation skills.

4. Aeronautical charts used in navigation training should be of the same type as those used in combat areas.

5. Methodological studies should be conducted to develop an inventory of visual training aids for use in formal and informal training of map-reading skills and to develop quantitative criteria for evaluating map-reading performance.

3. Campbell, W. R. Cartographic support for airborne navigation display systems - the role of government and industry. (U.S. Naval Oceanographic Office, Aeronautical Division.) Paper presented at the 26th Annual Meeting of American Congress of Surveying and Mapping, 1966.

4. Campbell, W. R. Mission annotation of microcharts. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. William R. Campbell presented an informal discussion of the need for a method of annotating the microcharts used in projected map displays. He described several design approaches and associated problems in satisfying this need, and summarized the status of Navy research efforts to develop a direct reduction marking system of annotation to support the A-7E projected map display. (This paper was not submitted for formal publication.)

5. Ferguson, T. G. Technical aspects of producing color transparencies for map displays. In J. J. McGrath (Ed.) Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. Thomas G. Ferguson described a system developed by the Eastman Kodak Company for producing map transparencies that are suitable for cockpit projection. The sensitometric characteristics of the system were discussed and recommendations were made for exposure and printing procedures. Mr. Ferguson also discussed the problems of defining acceptable prints and presented recommendations for controlling the quality of release prints.

6. Guttmann, E. S. The navigation chart as a design element of an integrated avionics system. In J. J. McGrath (Ed.), Aeronautical charts and map displays. Washington, DC: JANAIR, 1966.

This paper outlines the need for a map display in modern navigation and the types of map displays available. The relative advantages of each are discussed, and future research needs are noted.

7. Johnson, R. G. Map aids for low-level aviation. In J. J. McGrath (Ed.), Aircrew performance in Army aviation. Washington, DC: Office of the Chief of Research, Development and Acquisition, July 1974.

The Army aviator flying at low altitude requires a number of improvements of present map configurations in order to be maximally effective. Such improvements as enhanced portrayal of terrain relief, reduced bulk, highlighting of obstacles and landmarks, improved grid and

indexing systems were suggested. Since production of a new type of map for NOE flight is not practical within current resources, improvements can be made through modifications of existing maps. Additional areas of required research are outlined.

8. McGrath, J., Osterhoff, W., & Borden, G. Geographic orientation in aircraft pilots: Experimental studies of two cartographic variables (TR-751-3). Santa Barbara, CA: Human Factors Research, November 1964.

Two experiments were conducted to study the influence of cartographic variables on geographic orientation performance of pilots of light attack aircraft. A cinema method was used to simulate the visual aspects of low-altitude, VFR, navigation. The results of the first experiment showed that the removal of place names from a Sectional Aeronautical Chart produced no significant change in orientation performance. The second experiment showed that a change in chart scale, when information content remained the same, produced no significant change in orientation performance. However, a comparison of performances using the Sectional Aeronautical Chart and using the USAF Operational Navigation Chart showed that a change in scale, when accompanied by a change in information content, produced a significant change in orientation in low-altitude flight than the ONC. Implications of the results for navigation display design were discussed.

9. Misulia, M. G. Tailored products: A new era in cartography. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. Micheal G. Misulia reviewed the existing and anticipated future capabilities of the US Army Topographic Command to respond to a variety of user requirements. Cartographic products today generally represent a compromise of various user requirements because of the tedious manual operations and the inflexibility of the system and materials employed in responding to a customer's request. Mr. Misulia described the recent developments in the automation of various cartographic functions, as well as the technological breakthroughs in allied disciplines, that have revolutionized the processing operations and have provided for greater flexibility in product formats to permit cartographic products to be more rapidly tailored to meet special user requirements.

10. Osterhoff, W., Earl, W., & McGrath, J. Geographic orientation in aircraft pilots: Achromatic display of color-coded charts (TR-751-8). Goleta, CA: Human Factors Research, Inc., November 1966.

Geographic orientation performances of four groups of pilots were measured under conditions of simulated, VFR flight. The first used a full-color standard Sectional chart. The second group used a graytone version. The third group used a black-and-white line version. The fourth group used a blank version. Pilots who used the achromatic graytone and line charts performed significantly poorer than pilots who used color charts, but better than pilots using blank charts. The main reasons for the inferiority of the achromatic charts were: (1) categories of topographic information were difficult to differentiate; (2) reliance on natural landmarks had to be abondoned in favor of reliance on cultural landmarks; (3) pilots had to spend too much time studying the charts during flight; and (4) the vertical development of terrain was poorly portrayed. It was concluded that navigation display systems which lack color capability cannot effectively employ existing color-coded aeronautical charts. Specifically designed achromatic graphics will be required for such systems.

11. Osterhoff, W., & McGrath, J. Geographic orientation in aircraft pilots: Contemporary charts and pilot performance (TR-751-6) Santa Barbara, CA: Human Factors Research, May 1966.

Three different aeronautical charts were evaluated in terms of their relative effectiveness as visual navigation aids. Geographic orientation performances of three groups of pilots were measured under conditions of simulated, VFR, flight. One group used the Sectional Aeronautical Chart, another used the Operational Navigation Chart (ONC), and a third used the Pilotage Chart (PC). After a practice sortie, each pilot flew two test sorties over different routes of simulated flight.

The poorest performances were achieved with the PC on one route and with the ONC on the other route. Pilots using the Sectional performed as well as or better than those using either the PC or the ONC on both routes.

An explanation of the complex results was offered, based on the theoretical model suggested in an earlier report. The model accounted for the experimental results in terms of the orientation strategies adopted by the pilots under different conditions of flight. It was concluded that the relative effectiveness of aeronautical charts is specific to the terrain over which the pilots must navigate. The PC was an effective navigation aid when used over terrain having a substantial number of visual landmarks, but was less effective than other charts when used over terrain having few available landmarks.

12. Pelton, F. M., & Magonan, T. R. Chart requirements for low-altitude, high-speed, military missions. In J. J. McGrath (Ed), Aeronautical charts and map displays. Washington, DC: JANAIR, 1966.

The specification of charts for use in low-altitude, high-speed (LAHS) penetrations is very complex and as yet largely undefined. Some of the many questions which require answers are presented. The need for specialized maps for LAHS flight is presented and justified.

13. Self, J. K. MC & G products in tactical air operations. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

LTC Jimmy K. Self presented a general survey of the major products of mapping, charting, and geodesy (MC&G) that are currently used in tactical air operations. Experiences relating to the products, based on LTC Self's background as a pilot, ACIC Requirements Program Manager, and Forward Air Controller, were also briefly noted.

14. Shontz, W. D. Color coding for information location in geographic orientation tasks. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Dr. William D. Shontz reported the results of an investigation of visual search performance on an experimental geographic orientation task. The study was designed to evaluate the effects of color coding the locations of checkpoints, the number of coded categories, the number of objects per category, and background clutter. In general, the findings indicated that color coding for information location would be most effective when many categories of information can or must be coded, colors highly discriminable in peripheral vision are used, and the number of objects per category is less than twelve.

15. Steakley, J. E. Digital charting for future air navigation systems. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. Joe E. Steakley discussed the impact of rapid improvements in airborne computers, inertial platforms, airborne radars, and altimeters on new requirements for aerospace charting. These avionics advances and the mechanization of ground sensing and correlation with onboard data call for a new approach in the format of navigation aids. Mr. Steakley visualized an ultimate requirement for supplying many navigation materials in direct machine-usable form. Some of these cartographic forms discussed in the paper include both analog and digital high-resolution matrices of terrain portrayal.

16. Steingard, N., & Choha, D. Military standards for multicolor microchart transparencies. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR' 1969.

Mr. Nelson Steingard and Mr. Deforest Choha introduced a new military standard, applying specifically to map transparencies used in airborne display systems. The requirements that led to the need for the standard, the inter-service working group that prepared the standard, and the anticipated use and impact of the standard were enumerated and discussed.

17. U.S. Army Combat Developments Experimentation Command. Test of new and improved maps and map products (MAPPRO), Phase IV. Fort Ord, CA: Army Combat Developments Experimentation Command, June 1974. (AD 920 166L)

MAPPRO IV was designed to test the utility of six map products in assisting Army aviator and aerial observers in the performance of typical tasks during daylight hours. The tasks included trials using cross country navigation over 20 kilometer routes employing simulated NOE (nap of the earth) techniques and trials requiring position location estimates of point targets from a fixed holding pattern orbit at a specified altitude and speed. Player performance showed that the enhanced 1:50,000 orthophoto was the top ranked product. Other products tested were; 1:50,000 and 1:100,000 topographic line enhanced and unenhanced, 1:100,000 orthophoto, and 1:50,000 unenhanced orthophoto.

B. MAP DISPLAYS

1. GENERAL COMMENTS ON MAP DISPLAYS

1. Eddowes, E. E. The positioning of map navigation displays in aircraft cockpits: An analysis of requirements and restraints. In J. J. McGrath (Ed.), Aeronautical charts and map displays. Washington, DC: JANAIR, 1966.

The intention of this discussion is: 1) to point out again the fact that often beautifully executed equipment designs suffer from non-optimal positioning within the cockpit; 2) to suggest a rationale for optimum positioning of a map navigation display; and 3) to mention an equipment alternative or two for a visual navigation display.

2. Edmonds, E., & Wright 'R. The effects of map scale on position location (TR-65-9). Alexandria, VA: Human Resources Research Office, September 1965.

This study was conducted to determine the relationship between field position location and map scale. Two map scales were used 1:25,000 and 1:250,000. Twelve subjects were required to mark their position on a map at each of 12 terrain positions. The task was then repeated, utilizing the other scale map. The error in position location was approximately 10 times greater with the 1:250,000 scale map than with the 1:25,000 scale map. However, a significant scale-by-position interaction was found. It was concluded that maps of 1:100,000 or 1:125,000 scale would best meet the tactical target area requirements of Army aviators, and that the 1:250,000 scale map, with certain format changes, would provide the information necessary for en route tactical navigation over moderate or long distances.

3. McGrath, J. J. (Ed.) Aeronautical charts and map displays. Washington, DC: JANAIR, 1966.

This report presents the results of a symposium held to gather together the leading authorities in the various technological fields relevant to aeronautical charts and map displays to facilitate the exchange of information and ideas. Emphasis was placed on integration of cartographic products into navigation display systems.

4. McGrath, J. J. Contemporary map displays. NATO AGARD Conference Proceedings No. 96, Guidance and Control Displays, Paris, February 1972.

The purpose of this paper is to present a general review of developments and capabilities in airborne map-display systems and to summarize some of the current issues or problems in their design and use. The content of the paper is based on data collected by the author in studies of map displays conducted for the Joint Army-Navy Aircraft Instrumentation Research (JANAIR) program, but no attempt is made to report the detailed results of those studies nor to discuss the finely technical aspects of map-display design. Rather, the paper is aimed at acquainting the conference delegates with the principal concepts and general issues in this field.

Contemporary map displays derive from a complicated history of research, development and operational use. A brief overview of this history is presented first, and then the development of each of four basic types of map displays is traced from its origin to its present status. The four types are: direct-view map displays, projected map displays, combined map/CRT displays, and electronically generated map displays. The main advantages and limitations of each type are noted, and the various ways in which the basic design concepts have been implemented are described. Following this review, a number of design issues and operational problems of current importance are identified and briefly discussed. Finally, some guesses are offered concerning the role of map displays in military and civilian aviation during the remainder of this decade.

5. McGrath, J. J. The display of aeronautical charts. In S. Domeshek (Ed.), AGARD Avionics Panel Symposium on Problems of the Cockpit Environment. Conference Proceedings No. 55, NATO, 1970.

6. Ramsayer, K., Development of and experiences with map displays. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Prof. Dr. -Ing. Karl Ramsayer reviewed the map-display developments that have taken place in West Germany. The Institute of Air Navigation of the University of Stuttgart has developed two map displays designed to use aeronautical charts in their original sizes. One display was designed for use in aircraft that have a navigator in the crew and the other for use in aircraft without navigators. After describing some characteristics features of these displays, Prof. Ramsayer presented results from field trials. Some requirements for further development were summarized.

7. Roscoe, S. N. Some thoughts on map displays. In J. J. McGrath (Ed.), Aeronautical charts and map displays. Washington, DC: JANAIR, 1966.

The justifications and needs for map displays are first discussed, followed by the identification of three critical issues: information requirements, information formats, cartographic support. Some considerations of display effectiveness are also discussed.

8. Wilson, J. F. An improved terrain and elevation display for visual aeronautical charts. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. Joe F. Wilson described two experimental prototype charts, developed by the U.S. Coast and Geodetic Survey, which demonstrate that the terrain and elevation display shown on visual aeronautical charts can be improved by changing the color arrangement of the elevation gradient tints, by reducing the number of contour lines shown, and by overprinting the gradient tints and contours with fully shaded and highlighted relief portrayals rendered to match the details of the contours and printed in black. Mr. Wilson suggested that this form of terrain portrayal might be utilized in new concepts of graphics for geographic orientation of pilots of high-performance aircraft.

9. Wright, R. H. Some comments on the display of cartographic information for very low level flight. In J. J. McGrath (Ed.), Aeronautical charts and map displays. Washington, DC: JANAIR, 1966.

The basic task in navigation is the comparison of terrain information with cartographic information. At very low levels the terrain cues available to the aircrew are significantly different from those available at higher altitudes. Cartographic navigational aids should be specially designed for low level flight to maximuze the utility of the available cues.

2. DISPLAY CHARACTERISTICS AND DESCRIPTIONS

1. Bardox, A., Kalman, G., & Kearney, R. Holographic color map storage (Final Rept. under NASC Contract No. N00019-68-C-0097). Bristol, CT: Cargan Labs, January 1969.

2. Buis, T., & Swisher, J. Feasibility study to interface a map plotter with a LORAN C/D navigator (LWL-TM-71-06). Aberdeen Proving Ground, MD: Army Land Warfare Laboratory, November 1971. (AD 893 988L)

The object of the study was to determine the effort that would be required in order to interface a LORAL, Model TND-4, Map Plotter with a LITCOM, LORAN C/D, Model LRN-101, navigator. This study indicated that the interface was feasible. The next step should be to construct a working model and flight test the unit mounted in the U.S. Army's UH-1 series helicopter.

3. Carel, W., McGrath, J., Hershberger, M., & Herman, J. Design criteria for airborne map displays. Volume II: Design criteria (JANAIR Rept. No. 731101). Culver City, CA: Hughes Aircraft Co., March 1974.

This is the final report of research conducted under ONR contract N00014-71-C-0070, NR 213-075 entitled development of design criteria for projected map displays. Volume 2 consists of the statement of the design criteria. The criteria described are grouped under two main headings: (1) The displayed map image and (2) Other design issues. Criteria appropriate to the displayed map image were developed from operational requirements and from legibility requirements. Criteria appropriated to other design issues deal with features of map displays that are not directly related to the displayed map image; i.e., operating modes, controls, updating, and the like.

4. Carel, W., McGrath, J., Hershberger, M., & Herman, J. Design criteria for airborne map displays. Volume I: Methodology and research results (JANAIR Rept. No. 731101). Culver City, CA: Hughes Aircraft Co., March 1974.

The work accomplished under the contract is reported in two volumes. Volume I describes the methods used to develop the design criteria and the results of the surveys, analyses, and experimental research conducted in the course of the program. The research is categorized under the following headings: (1) Mission requirements analysis, (2) The legibility problem, (3) A survey of contemporary map displays, (4) A survey of users of operational map displays, and (5) A survey of contemporary cartographic support systems.

5. Dougherty, D., Abbot, B., & Matheny, W. A study of simulated rotary wing hovering performance as a function of symbol heading using a moving symbol - fixed map pictorial position display. Ft. Worth, TX: Bell Helicopter Co., September 1961. (AD 265 586)

This report describes the first in a series of studies in the ANIP program designed to examine rotary-wing, VTOL and GEM system requirements for pictorial position displays. This study was designed to examine the ANIP display philosophy and the rotary wing maneuvers, an experiment which would permit comparison with research results of fixed-wing studies. The purpose of this study was to examine pilot performance in maintaining hovering position when using a simplified simulated rotary-wing flight system. The experimental variables were: symbol heading on a fixed map-moving aircraft and inclusion of an earth grid attitude display (contact analog or vertical display).

6. Honick, K. R. A topographic navigational display. Aeronautics, 1961, 45-1.

7. Honick, K. R. The development of topographical navigation displays in the United Kingdom. In J. J. McGrath (Ed.), Aeronautical charts and map displays. Washington, DC: JANAIR, 1966.

Describes the development of map displays in the U.K. Strip, projected and combined map - CRT displays are discussed in terms of historical and current development.

8. Kaelin, G., & Pellegrino, J. Study of the integration of a multi-color panel display with military maps. Van Nuys, CA: Litton Systems, May 1970.

9. McGrath, J. Comments on human factors in the design of an electroluminescent map display (Tech. Note No. 114-1). Santa Barbara, CA: Anacapa Sciences, September 1969.

10. Scott, D. Trials on a topographical map display mode by Computing Devices of Canada (EE/TECH/299/NAV). Boscombe Down, Eng.: Aeroplane and Armament Experimental Establishment, 1964.

11. Suvada, T. C. Development of a combined map/CRT display for the F-111 aircraft. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. Thomas Suvada described the navigation display system developed for the F-111. The system's unique is its capability of projecting an aeronautical chart onto the phosphor screen of a rear-ported CRT. The CRT's capability for character generation is then used to provide an annotation capability for the map display. Displays of this type encounter severe legibility problems in the cockpit environment; Mr. Suvada described the special efforts made to solve those problems.

12. Vajo, V. Digital generation of contour maps for raster scan display (ECOM-4454). Ft. Monmouth, NJ: Army Electronics Command, December 1976. (AD A034 663)

This report is concerned with the development of a digitally generated contour map to be displayed on standard raster TV for use in Army aircraft.

The requirement for a display of this type is generated by the operations of Army aircraft in nap-of-the-earth (NOE) flight during both day and night operation. NOE flight in this case refers specifically to pilotage at or below tree top level.

The study proved the feasibility of generating digital contour maps for display on standard TV monitors. Computer programs were written in assembly language for the Singer SKC-2000 Airborne Computer which generate two color (black and white) contour maps for display on a standard 525 line television system.

13. Winner, R., & Ernstuff, M. A color television monitor for the display of standard aeronautical charts in advanced tactical aircraft: A design study (Tech. Rept. under NADC Contract No. N62269-70-C-0381). Culver City, CA: Hughes Aircraft Co., March 1971.

3. MOVING MAP DISPLAYS

1. Burton, G., Clay, B., Croce, R., & Gore, D. Laser-hologram multi-color moving map display system (Final Rept. under NASC Contract No. N62269-70-C-0080). Burlington, MA: RCA Advanced Technology Laboratory, November 1970.

2. Gracey, W., Summa, R., & Tibbs, D. Evaluation of a moving map instrument display in landing approaches with a helicopter (TN-D-3986). Hampton, VA: NASA Langley Research Center, May 1967.

3. Hitchcock, L. Readability of videotaped moving map displays. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Dr. Lloyd Hitchcock reported a study that was conducted to answer some basic questions about the readability of videotaped moving-map displays. Specifically, the study was concerned with (1) establishing criteria for the minimum size of map legends, (2) the effect of map orientation upon legend readability, (3) the effects of color upon readability, and (4) the effect of rotating the maps from north oriented to course oriented upon the pilot's ability to estimate point-to-point headings. The findings indicated that minimum character height should

subtend 35 minutes of visual angle at 25-inch viewing distance and should traverse at least seven TV raster lines. Readability of color presentation was less than black-and-white. Orientation tended to increase heading estimation errors, but did not affect readability.

4. McKechnie, D. Comparison of a moving map display and two graphics with hand-held maps (AMRL-TR-69-110). Wright-Patterson AFB, OH: Aerospace Medical Research Laboratory, May 1970.

5. McKechnie, D. F. The use of hand-held maps and a moving map display with a strip map or strip photo in a simple flying task. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. Don F. McKechnie reported the flight test of a Bendix Moving Map Display in a Cessna 02A aircraft. The results showed that pilots have generally unfavorable opinions of the display, yet they performed better with it. Both the magnitude and variability of navigation errors were largest with the hand-held map and smallest with the map display incorporating the strip photo.

6. Roscoe, S. N. Case for the moving map display. Information Display, 1967, Sep;Oct., 44-46.

7. Vickers, T. K. Application of moving map displays in marine and air navigation. SID Quarterly Proceedings, 1969, 10(2).

4. PROJECTED MAP DISPLAYS

1. Allen, R., & Starke, R. Operational test and evaluation AN/APN-31 doppler navigation system with Laboratory for Electronics map display set (TR-61-36B). Langley AFB, VA: Tactical Air Command, June 1963.

2. Anderson, D. W. Desirable design features peculiar to a projected moving map display. In J. J. McGrath (Ed.), Aeronautical charts and map displays. Washington, DC: JANAIR, 1966.

The projected film-strip technique for a moving-map display appears ideal for the low-level tactical role. Recommendations include: 1:500,000 pilotage charts, 1:2,000,000 JN charts, 5000 foot-lamberts screen luminance, display maximum error of .08 inches, related symbology and controls should be limited to those required for proper function of the display.

3. Boot, A. Cartographic support of projected map displays for civil aviation. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. Alan Boot described the cartographic support of the projected map display that will be used in the Concorde supersonic transport and commented on the various aspects of map microfilming in general. The factors that influence the choice of projection, map content, film type, and the techniques of map and filmstrip production were discussed.

4. Braid, J. M. Radar/map matching in navigation and attack. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. James M. Braid discussed techniques and equipment for radar/map matching, and showed how they are cost-effective in modern navigation and attack systems. Mr. Braid's main message was that the advantages of radar/map matching can be obtained with negligible penalties by recognizing the advantages conferred by modern moving-map displays coupled to the more accurate navigation systems now available and by avoiding the misconception of believing that absolutely distortion-free map and radar images must be produced for accurate updating.

5. Defoe, R. M. Filmstrip support of the projected map display system AN/ASN-99. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. Roger M. Defoe described portions of the cartographic support program provided for the projected map display installed in the A-7E light attack aircraft. Items discussed included navigation charts, frame preparation, film selection, microphotography, and environmental consideration in producing 35-mm cartographic filmstrips.

6. Emtage, J., & Carter, P. Flight trials of a Computing Devices of Canada projection map display (16^{th} Part of Rept. No. 931/1). Boscombe Down, Eng.: Aeroplane and Armament Experimental Establishment, September 1968.

7. Fromm, H. J., & Gray, W. C. Photographic annotation material for projected map displays. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. Harold J. Fromm and Mr. William C. Gray contributed a paper describing a method by which color transparencies of aeronautical charts can be photographically annotated by overcoating the gelatin layer of the processed color film with a photosensitive diazo layer. The annotated layer can conveniently be removed by treatment with a suitable solvent, so that the annotation procedure can be repeated many times on the same color transparency.

8. Honick, K. R. Microphotographic support of projected map displays in service. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. Kenneth R. Honick described the organization, procedures, and equipment developed in the United Kingdom to provide logistic support of projection-type navigation displays. The logistics involve the preparation and supply of cartographic filmstrips in quantity. Mr. Honick discussed the characteristics of continuous-flow copying techniques that were developed to solve the problem and proposed standardization of filmstrips made for displays operated by digital computers.

9. Macnab, R., & Alexander, J., Projected map navigation in military helicopters-applications and operational experience. AGARD Conference Proceedings 86-71, September 1971.

Computing Devices of Canada has had more military flight experience with Projected Map Displays than any other organization in the world. This experience includes six one-of-a-kind flight evaluations, three of these conducted in helicopters. The production Projected Map Display (AN/ASN99) has accumulated over 50,000 hours of service in the U.S. Navy A-7E attack aircraft. The lessons learned from our experience have confirmed that this system is an ideal navigation display system for military tactical aircraft, particularly helicopters.

This paper explains the reasons for this conclusion in detail, and by documented comment from flight trial reports. It also explains why Projected Map systems are fundamentally superior to present day conventional navigation systems. Finally, the paper recommends a Projected Map System tailored for helicopter application; which has been developed to the flyable prototype stage by Computing Devices.

10. Mueller, A. W. Cartometric requirements and photochemical instrumentation for projected map display filmstrips. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. Arvin W. Mueller described the production and quality control procedures used to produce two different kinds of map transparencies for cockpit displays. Emphasis was given to the specialized equipment required for such production and the mensuration qualities required of the filmstrips.

11. Tayler, J., & Carter, P. Flight trials of a Marconi AD 670 computer and projected map display (AAEE/TECH/405/NAV). Boscombe Down, Eng.: Aeroplane and Armament Experimental Establishment, October 1969.

The Marconi AD 670 navigation computer and projected map display was flight tested in Wessex MK, 2 XS 679 to determine its accuracy, reliability and suitability as a helicopter display. The system incorporates a digital computer which during the trial accepted information from an AD510 doppler and a GM7B compass. The accuracy was found to be very good, but the reliability was poor. The equipment was found to be a valuable aid to navigation, but several improvements are recommended.

5. ROLLER MAP DISPLAYS

1. Abraham, H., & Campbell, W. Cartographic considerations for roller map design (Rept. No. 17339-2). Washington, DC: US Naval Oceanographic Office, 1966.

This report analyzes those cartographic considerations pertinent to the design of a roller map type of navigation display system. Design approach is discussed and a historical development is briefed. The report discusses the variety of charts, scales, and projections available, necessary corrections, chart orientation, relative movements, and preparation of a chart strip. Some desired capabilities of a roller map display system are presented.

2. Emtage, J. Decca Mk. 5 Roller Map flight trials of a production version in a Wessex helicopter (TRC-BR-26047). Boscombe Down, Eng.: Aeroplane and Armament Experimental Establishment, July 1971. (AD 902 616L)

The Decca Mk 5 Roller Map was tested in a large variety of roles, ranging from tactical low flying to en-route navigation. It was flown at night and in bad weather, and over both familiar and unfamiliar terrain. Altogether the equipment was flown for a total of 90 hours, and it remained fully serviceable for the duration of the trial. It was a useful aid to navigation in all the roles in which it was flown, its major contribution being the reduction of in-flight cockpit work load.

3. Emtage, J., & Carter, P. Flight trials of Decca Mk. 5 Roller Map in Wessex Mk. 2 X5 679 (AAEE/TECH/392/NAV). Boscombe Down, Eng.: Aeroplane and Armament Experimental Establishment, November 1968.

The first experimental Decca Mk. 5 roller map was flown for 17 and ½ hours in Wessex Mk. 2 X5 679 at A and AEE Boscombe Down. This report covers pilot opinion of the Mk. 5 Roller map and its controls, and an accuracy assessment of a navigation system incorporating the Mk. 5 roller map when operating under demanding conditions.

4. McInerney, J., Haag, J., & Starke, R. Operational test and evaluation of the Decca Roller Map (TR-62-60). Langley AFB, VA: Tactical Air Command, January 1964.

CHAPTER V

AVIONICS EQUIPMENT

This chapter contains literature references relating to electronic and electro-mechanical devices used for navigation purposes such as avionics packages, horizonatal situation indicators, compasses, hover displays. These devices include analog and symbolic devices used to portray navigation information.

1. Bass, S. D. Horizontal situation display for the integrated helicopter avionics system. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. Saul D. Bass described the development of a horizontal situation display for use in Marine Corps assault helicopters as part of the IHAS program. A design that utilizes a paper roller map superimposed on the face of a direct-view CRT equipped with a fiber optics face plate was chosen, because it was felt that a system that required special cartographic materials could not be supported in the field. Mr. Bass described how several prototype display systems and map-preparation devices were developed and performed satisfactorily during the IHAS flight test program and system effectiveness demonstration.

2. Gibb, G. Scout A.H. Mk. 1 evaluation of G4F compass installation (AAEE/935-Pt-9). Boscombe Down, Eng.: Aeroplane and Armament Experimental Establishment, February 1966. (AD 481 092)

An evaluation of the G4F compass installation has been carried out in Scout A.H. Mk. 1, XP 847. Some of the compass deviations do not strictly meet Av. P. 970 requirements, but in view of the type and role of the aircraft and the difficulties involved in re-siting the compass detector unit, C.A. release is recommended.

3. Gosciniak, T. Initial production test of radio-magnetic compass indicator ID-998/ASN. Ft. Huachuca, AZ: Army Electronic Proving Ground, October 1970. (AD 877 817L)

An Initial Production Test (IPT) of the Radio-Magnetic Compass Indicator ID-998/ASN, was conducted at the US Army Electronic Proving Ground (USAEPG), Fort Huachuca, Arizona from May to October 1970. The purpose of the test was to determine the engineering adequacy, technical performance, maintainability, safety characteristics, and operational performance of the test item. Four test items were available for use.

4. Governmental Affairs Institute. Avionics for light observation helicopter. Washington, DC: Government Affairs Institute Research Division, October 1968. (AD 853 367)

Light observation helicopter (LOH) avionics consist of lightweight communication, navigation, and identification equipment to be used primarily in the Cayuse OH-6A helicopter. VHF-FM, VHF-AM, and UHF-AM radio transceivers, two communication controls, an IFF transponder system, an automatic direction finder, a gyromagnetic compass set, and associated antennas, cabling, controls, and test equipment are included and are in limited production. The transceiver sets were designed for maximum commonality of parts, maintainability, and flexibility for improvement, growth, and varied uses.

5. Hammond, J. Trial of a Marconi AD370 radio compass in Wessex-XS 679 (AAEE/Tech/384/Rad). Boscombe Down, Eng.: Aeroplane and Armament Experimental Establishment, November 1968. (AD 846 521)

Following trials of the Marconi Radio Compass AD 370 in Comet XS 235 a trial was conducted to evaluate the performance of the system in a helicopter environment. Air calibrating swings were used to evaluate the basic accuracy which was found to be within specification limits. In addition the performance was observed during a tactical sortie involving a large number of maneuvers, and the range performance was chekced. In all aspects the performance was satisfactory.

6. Ivey, J. Engineering test of Standard Lightweight Avionics Equipment (SLAE), formerly Light Observation Helicopter Avionics Package (LOHAP) (USAEPG-FR-282). Ft. Huachuca, AZ: Army Electronic Proving Ground, August 1970. (AD 874 496L)

The SLAE was designed to be a lightweight, easily maintainable, and highly reliable communications-navigation package consisting of three transceivers, an automatic direction finder (ADF) with amplitude modulation (AM) radio receiver, two control units, the associated antennas, and a maintenance kit.

7. Ostheimer, A. Equipment description of a flight path control system for helicopter/VTOL aircraft (HSER-3098). Broad Brook, CT: Hamilton Standard Electronics, May 1965. (AD 473 803L)

The flight path control system consists of an inertial navigation system (Gimbal-less) and an automatic stabilization system which has couplers in pitch, roll, yaw, and collective. The system uses strapped down inertial sensors to provide the basic inputs of vehicle angular rates, and linear accelerations. Three gyros and three accelerometers provide the signals necessary to perform the basic navigation function. The FPC contains a stored flight plan which when compared to the present position of the helicopter generates command signals to automatically fly the vehicle to its pre-programmed destination. These command signals are applied through a modified SH3A helicopter Automatic Stabilization Equipment autopilot to actuate the vehicles flight control system.

8. Pittsburgh University. Aircraft navigation computer (ANC). Washington, DC: Pittsburgh University Research Staff, January 1968. (AD 827 528)

The aircraft navigation computer (ANC) is a low-cost, miniature, self-contained system for computing and indicating present position. It is designed to free pilots of light observation aircraft from most of the chores and chances for error that go with navigation by manual dead reckoning. Outputs of computing circuits automatically move a precut section of map up or down and a transparent cursor strip right or left across the map display to show the current position of the aircraft.

9. Pittsburgh University. Development of Advanced Army Aircraft Instrumentation System (AAAIS). Pittsburgh, PA: Pittsburgh University, August 1964. (AD 450 764)

Designed to lessen the instrumentation burden on pilots of modern Army aircraft, the advanced Army aircraft instrumentation system (AAAIS) will simplify flight management problems, reduce computational work loads, replace many conventional cockpit instruments, and present to the pilot inside the cockpit a representation of the area in front of the aircraft. It will give the pilot the same visual cues in inclement weather as he would normally have in clear weather. The system at this point is in the installation and systems check phase. The rotary-wing system, referred to as the helicopter cockpit instrumentation system (HCIS) is scheduled for installation in mid-1965.

10. Slattery, J. Proposed inflight human factors evaluation plan for advanced Army aircraft instrumentation system (AAIS) criterion development/ initial evaluation phase. Aberdeen Proving Ground, MD: US Army Human Engineering Laboratory, 1966.

11. Sytin, Y., Chupina, K., Shpolyanskii, S., & Yanin, V. Avionics and radio electronic equipment for KA-26 helicopter (FSTC-18-77). Charlottesville, VA: Army Foreign Science and Technology Center, July 1977. (AD B023 616L)

This volume describes the configuration, operating principle, and operating characteristics of the electrical equipment, electric power sources, flight and navigation instruments, radio equipment, cockpit, aircraft and avionic equipment, and also of the instruments for monitoring the helicopter engines, systems and components. The book is intended for engineering and technical personnel and flight crews of the civil aviation operational units. It may also be used by the students of the technical training organizations and aviation schools.

12. Thomas, T. Design of a simulator horizontal tactical display. Johnsville, PA: Naval Air Development Center, February 1969. (AD 852 910L)

This report covers the design and development of a simulated Horizontal Tactical Display. The device is a mechanized map display using digital logic to control map movement and present position indication. This display was used in the cockpit of the IHAS flight simulator.

13. Tsoubanos, C. An investigation of displayed ground referenced position, velocity and acceleration for precision hover (ECOM-4334). Ft. Monmouth, NJ: Army Electronics Command, July 1975. (AD A012 813)

This report presents a man-machine simulation investigation of displayed ground referenced acceleration, velocity, and position for a manual precision hover task. The study determined the appropriate display gains for the above parameters as a function of three different control systems: the Automatic Stabilization Equipment (ASE), the Stability Augmentation System (SAS) and the Hover Augmentation System (HAS).

14. US Army Electronics Laboratories. Advanced Army aircraft instrumentation system and helicopter cockpit instrumentation system. Ft. Monmouth, NJ: Army Electronics Laboratories, July 1964. (AD461 996)

The Advanced Army Aircraft Instrumentation System (AAAIS) is designed to provide the aircraft (Heavy Observation Aircraft) (HOA) with the selfcontained capability for low level flight in all conditions of visibility as required to accomplish the tactical mission; permit the pilot to make optimum use of the aircraft's maximum performance characteristics: and to minimize flight and instrument training. The design plan is the detailed technical approach, on a systems engineering basis, for the fabrication and installation of the AAAIS in the Beech Model J-50 (U-8) aircraft and the Bell Helicopter Model UH-1B helicopter.

15. Wilkerson, L., & Matheny, W. An evaluation of grid encodement of the ground plane as a helicopter hovering display. Ft. Worth, TX: Bell Helicopter Co., October 1961. (AD 268 273)

16. Wroten, C. Service test of the AN/ASN-62() gyromagnetic compass set. Ft. Rucker, AL: Army Aviation Test Board, February 1966. (AD 479 983L)

The US Army Aviation Test Board service tested the AN/ASN-62() Gyromagnetic Compass Set installed in an OV-1B Airplane and CH-34C Helicopter at Fort Rucker, Alabama, during the period 15 March to 30 December 1965.

CHAPTER VI

RESEARCH METHODOLOGY PERFORMANCE MEASUREMENT, SIMULATION, AND TRAINING

The literature in the chapter classifies that literature which identifies navigation experimentation techniques. It is intended to provide the reader with sources of information on navigation experiments, methodologies, and performance measures.

1. Borden, G. Geographic orientation in aircraft pilots: Post-flight method of reporting navigation performance (HFRI-TR-751-10). Goleta, CA: Human Factors Research, December 1966.

2. Borden, G., & McGrath, J. Geographic orientation in aircraft pilots: A field validation of a post-flight method of reporting navigation performance (Tech. Rep. 751-14). Goleta, CA: Human Factors Research, July 1968.

In a previous study, a method was developed for obtaining navigational data from operational missions by means of postflight reports by the pilot. In this study, a series of flight tests were conducted to determine the validity of navigational data obtained by that method. Two fixed-wing squadrons and two rotary-wing squadrons flew a total of 39 low-altitude sorties, and an objective record of the track of each sortie was obtained. During fixed-wing sorties, the objective track was determined by chase pilots; during rotary-wing sorties it was determined by Decca Flight Logs. After each sortie, the pilot marked on his aeronautical chart the track he recalled having flown. Measurements of navigational errors were made from the objective tracks and compared with those made from the recalled tracks.

The results showed that pilots could readily achieve quarter-mile accuracy in recalling the track, and half-mile accuracy in recalling their positions along the track at specific moments in time. When sets of navigational errors measured from the objective tracks were compared with those measured from the recalled tracks, it was found that (1) the distributions were similar in shape, dispersion, and mean; (2) mean scores for individual sorties were highly correlated; and (3) mean flight profiles were highly correlated.

It was concluded that the postflight reporting method is a valid method for obtaining data for comparative studies of navigation performance, for normative studies, and for studies of trends in navigation performance.

3. Cummins, E. R. Development of user requirements: Methods and criteria. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

LtCol. Edward R. Cummins presented an overview of the requirement analysis and documentation procedures employed by the Aeronautical Chart and Information Center. The use and content of Requirement Guides and Product Review documentation were summarized. In addition, LtCol. Cummins described, as an example of ACIC procedures, the requirement analysis and review presently being accomplished for the 1:500,000-scale Tactical Pilotage Chart.

4. Farrell, J., & Fineberg, M. Specialized training vs. experience in helicopter navigation at extremely low altitudes (ARI-TP-277). Arlington, VA: Army Research Institute for the Behavioral and Social Sciences, November 1976. (AD A034 732)

An experiment was performed to determine if navigation skills acquired in general flight would transfer to flight at extremely low levels and if the transfer could be matched by specialized training. Since the effects of extensive experience were matched by only 15 hours of special training, transfer may not be as extensive as previously assumed.

5. Fineberg, M., Meister, D., & Farrell, J. P. Navigational and flight proficiency measurement of Army aviators under nap-of-the-earth conditions. Arlington, VA: US Army Research Institute for the Behavioral and Social Sciences, February 1975.

6. Herres, R., & Brandt, T. An analog simulation and analysis of an inertial navigation system for helicopter use. Wright-Patterson AFB, OH: Air Force Institute of Technology, March 1960. (AD 237 823)

7. Lewis, R. E. F. Navigation at very low level: Methods of evaluation. In J. J. McGrath (Ed.), Aircrew performance in Army aviation. Washington, DC: Office of the Chief of Research Development and Acquisition, July 1974.

Field testing is strongly advocated as the primary methodology of NOE performance research because flight trials more closely approximate operational conditions than do simulator studies, and the results are more meaningful to operational users. Several practical recommendations for conducting field trials are offered. Further field research is needed to define the clearance altitude requirements of NOE missions since this can greatly affect aircrew workload and stress.

8. Lewis, R. Pilot performance during low speed, low level navigation (DRML Rept. No. 248-1). Toronto, Canada: Defense Research Medical Laboratories, June 1961.

9. Lewis, R., & de la Riviere, W. A further study of pilot performance during extended low speed, low level navigation (DRML Rept. No. 248-2). Toronto, Canada: Defence Research Medical Laboratories, November 1962.

10. McGrath, J. A technical approach to the evaluation of navigation systems for Army helicopters. Santa Barbara, CA: Anacapa Sciences, Inc., May 1976.

The purpose of this study was to develop a technical approach to the test and evaluation aircraft. Assessing airborne navigation systems can be complex and costly, and can produce invalid results if not done properly. The objective of this study, therefore, was to develop a cost-effective test and evaluation approach. The study consisted primarily of reviews of the relevant literature and conferences with military, industrial and research personnel who had expert knowledge of various aspects of airborne navigation and test procedures.

11. McGrath, J., & Borden, G. Geographic orientation in aircraft pilots: A research method (Tech Rept. 751-2). Goleta, CA: Human Factors Reserach, September 1964.

12. McGrath, J., Christensen, P., & Osterhoff, W. Geographic orientation in aircraft pilots: Speed control inversion. (TR-751-7). Santa Barbara, CA: Human Factors Research, July 1966.

An experiment was conducted to investigate the incidence of inversion errors in the control of airspeed. Sixteen pilots were tested in a laboratory task that required them to make speed control decisions similar to those made during flight for the purpose of achieving a preplanned time of arrival. The results showed that pilots had little difficulty in deciding whether or not a change in speed was necessary, but frequently made errors in deciding which direction to change it. That is, pilots often decided to decrease speed when the correct response was to increase speed, and vice versa. The question of whether or not inversion errors in speed control occur during actual flight is discussed, and some of the factors that may influence the occurrence of such errors are examined.

13. McGrath, J., & Foster, E. Development of a system of aircrew training in nap-of-the-earth navigation (Final Rep. 215-1). Santa Barbara, CA: Anacapa Sciences, January 1975.

14. McGrath, J., Osterhoff, W., Seltzer, M., & Borden, G. Geographic orientation in aircraft pilots: Methodological advancement (Tech. Rept. 751-5). Goleta, CA: Human Factors Research, October 1965.

15. Murrell, J. F., & Hopkin, V. D., Experimental methods for evaluating maps. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

Mr. John F. Murrell and Mr: V. D. Hopkin described a variety of techniques for assessing map design by means of the behavioral analysis of the map user's performance. These included the measurement of user performance in search tasks, communication and liaison tasks, image correlation tasks, and navigation; the use of questionnaires; the experimental evaluation of elements of the map and their interactions; and multi-dimensional studies of judgments using maps. The results of studies using some of these methods were reported.

16. Niemela, J. Unique wide field of view visual simulation. Paper presented at the 11th Annual Conference on Manual Control, NASA Ames, 1975.

17. Sokolowski, S., & Fisher, M. Doppler sensor simulation model (ECOM-4411). Ft. Monmouth, NJ: US Army Electronics Command, May 1976.

Economic considerations require the investigation of alternatives to high precision navigation sensors. One alternative is a Hybrid Loran/Doppler system where components' accuracy specifications are somewhat relaxed. The hybrid system utilizes the long term position error stability of loran to restrain the divergent doppler error. The synthethis of such a system depends on the establishment of good computer simulation approach which, in turn, relies upon valid sensor models. Sensor model development begins with the constraints of Army mission requirements and a knowledge of the hardware, continues with the determination of an appropriate mathematical model, and concludes with a hardware verification phase. A doppler model was developed to be used in the system computer simulation. Major factors involved in the development of the sensor model are discussed in this report.

18. Stephenson, M. H., & Feuge, R. L. Navigation training simulators. Journal of the Institute of Navigation, 1972, 19, 241-250.

Honeywell is currently designing and manufacturing the Undergraduate Navigator Training System (UNTS) for the U.S. Air Force Aeronautical Systems Division and the Air Training Command.

This paper describes the design and human factors philosophy of the UNTS, an all-digital trainer that simulates a complete array of air navigation instruments. The discussion emphasizes in particular the training objectives to be met and how the trainer is designed to meet these objectives, and the simulation concepts employed to activate the navigation instruments.

19. Thomas, F. H. Aviator performance in the light weapons helicopter during nap-of-the-earth flight. Paper presented at the Tenth Army Human Factors Research & Development Conference, Ft. Rucker, AL, 5-8 October 1964, 133-141.

CHAPTER VII

SYMPOSIUMS AND BIBLIOGRAPHIES

1. Joint Army-Navy Aircraft Instrumentation Research Project. Bibliography of the Joint Army-Navy Aircraft Instrumentation Program (JANAIR-720101). Washington, DC: JANAIR, August 1972. (AD 903 890L)

Contents: Displays for Terrain Avoidance/Terrain Following: Integrated Cockpit Research Program; Displays for Helicopter Formation Flight; Displays for VTOL Steep Angle of Approach; Helicopter Lift Margin Performance Display; Displays and Controls for Search and Rescue Aircraft; Aircraft Optimum Multiple Flight Path Displays; Geographic Orientation of Aircraft Pilots; Theory of Manual Control for Displays; Aircraft Head-Up Displays; Integrated Electronic Aircraft Displays; Auditory Displays; Cockpit Geometry Evaluation; Radar; Display Media; Navigation Systems; Low-Airspeed Sensor; Subsystem Interconnect Techniques; and General.

2. McGrath, J. Geographic orientation in air operations. Proceedings of a symposium held at Washington, DC on 18-20 November 1969. Santa Barbara, CA: Anacapa Sciences, Inc., April 1970. (AD 709 124)

The document records the proceedings of a symposium on geographic orientation of aircraft pilots during various phases of air operations. The meeting was attended by experts in the fields of technology related to the development and use of aeronautical charts and map-display systems for manned aircraft. The principal topics of the symposium were user requirements, cartographic developments, map-display design, CRT/map displays, human factors and systems analysis studies, cartographic support of map displays, and field evaluations of map displays. The recorded proceedings include the manuscripts of a keynote address and 30 technical papers, edited transcripts of the discussions that followed the papers, summary reports of five special discussion groups, a special report of JANAIR research in this field, an overview of the symposium proceedings, and a directory of the participants.

3. McGrath, J. J. JANAIR studies of geographic orientation. In J. J. McGrath (Ed.), Geographic orientation in air operations. Washington, DC: JANAIR, 1969.

The first technical session of the symposium consisted of a special report of the JANAIR program of research on geographic orientation. Dr. James J. McGrath, the Principal Investigator in the program, summarized the operational problem of pilot orientation in low-altitude flight, described the experimental and analytical methods used to investigate the problem, and highlighted the results of studies conducted in the program. Selected recommendations for action were offered to the various professions represented by the symposium participants.

4. McGrath, J. (Ed.) Proceedings of Conference on Aircrew Performance in Army Aviation held at US Army Aviation Center, Ft. Rucker AL on November 27-29, 1973. Washington DC: Office of the Chief of Research, Development and Acquisition, July 1974. (AD A001 539)

The purpose of the conference was to explore the behavioral problems affecting pilots of Army helicopters, with special emphasis on Nap-of-the-Earth (NOE) flight. The technical papers included in this proceedings deal with the nature of the future combat environment, next generation helicopters, cockpit configuration, map aids, avionics systems, night vision devices, training and simulation requirements and measurement criteria. Included also is a recommended behavioral research program to support Army Aviation.

5. Upton, H., Willis, J., & Dougherty, D. 1964 Annual Joint Army-Navy Aircraft Instrumentation Research Progress Report (JANAIR-D288-100-009). Ft. Worth, Bell Helicopter Co., August 1964. (AD 617 602)

The report describes work which was accomplished in the areas of engineering and human factors flight tests of the RH-2 (Research Helicopter Number Two), human factors flight simulation evaluations of the contact analog vertical display, and experimentation of map features for the navigation display. The evaluative studies are presented with performance data and brief results and conclusions.